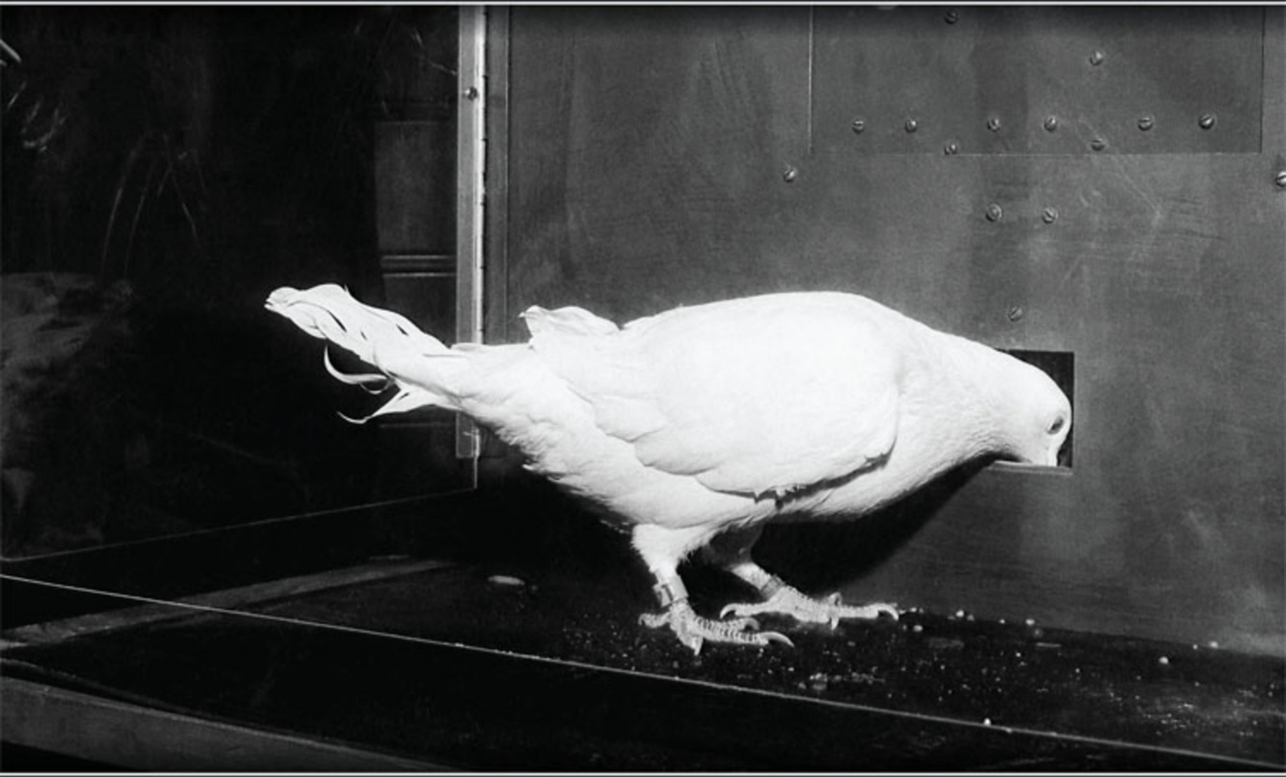

Edited by
Frances K. McSweeney and Eric S. Murphy

THE WILEY BLACKWELL HANDBOOK OF *Operant and Classical Conditioning*

WILEY Blackwell

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Jonathan C. Baker is an Associate Professor in the Behavior Analysis and Therapy Program in the Rehabilitation Institute at Southern Illinois University (SIU) and coordinator of the Graduate Certificate in Gerontology at SIU. He received his Ph.D. from Western Michigan University (2009) in Behavioral Psychology, an M.S. (2005) in Applied Behavioral Sciences and a certificate in Gerontology from the University of Kansas. He is a Doctoral-level Board Certified Behavior Analyst and serves on the Editorial Board of *The Analysis of Verbal Behavior*, as well as a guest reviewer for *the Journal of Applied Behavior Analysis*, the *Journal of Organizational Behavior*

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Mark E. Bouton, Ph.D, is the Lawson Green and Gold Professor of Psychology at the University of Vermont. He has studied extinction, and the effects of context on extinction learning and extinction performance, for over three decades. He is the author of a textbook on learning theory (*Learning and behavior: A contemporary synthesis*, published in 2007 by Sinauer Associates), of which he is busily writing a second edition, He has received a number of awards, including the Gantt Medal from the Pavlovian Society, and he is a Fellow of several scientific organizations, including the American Psychological Association, the Association for Psychological Science, and the Society of Experimental Psychologists.

Andrew R. Craig grew up in southwestern Pennsylvania and attended West Virginia University as an undergraduate. Under the mentorship of Drs. Kennon Lattal and Elizabeth Kyonka, he developed interests in behavior analysis, generally, and the quantitative analysis of behavior, particularly. Andrew earned his B.S. degree in Psychology in 2011. He then traded the rolling hills of Appalachia for the peaks of the Rocky Mountains when he enrolled as a doctoral student in the Psychology Department at Utah State University. His advisor is Dr. Timothy Shahan. His recent work focuses on examining the genesis of behavioral momentum and why momentum theory applies to some situations but not to others. He and Dr. Shahan are involved in collaborative efforts with Dr. John Nevin aimed at applying momentum theory to complex clinical situations and with Dr. Charles Gallistel aimed at quantifying the operant contingency in terms of information theory.

Kimberly A. Crosland, Ph.D., BCBA-D, is an Assistant Professor in the Applied Behavior Analysis Program in the Department of Child and Family Studies at the University of South Florida. Her research interests are in the area of behavioral assessment, caregiver training, child welfare, and developmental disabilities. She has received federal funding from the Department of Education to support her research to develop effective interventions to improve outcomes for youth in foster care.

Sabrina M. Darrow is currently a Postdoctoral Fellow in the Department of Psychiatry at the University of California, San Francisco. She received her doctorate in Clinical Psychology in 2011 from the University of Nevada, Reno where she developed expertise in third-wave behavior therapies, particularly Functional Analytic Psychotherapy, and psychotherapy outcome research methodology. During her post-doctoral fellowship in the Clinical Services Research Training Program at University of California, San Francisco she consulted on many mental health services research projects and built expertise in measurement development. Her primary research interests include the clinical utility of assessment, clinical behavior analysis, mechanisms of action in psychotherapy, and implementation research.

Michael S. Fanselow, Ph.D., is a Distinguished Professor in both the Psychology and Psychiatry Departments at University of California Los Angeles (UCLA). He currently holds the Eleanor Leslie Chair in Innovative Neuroscience through UCLA's Brain Research Institute. His research is on the neurobiology of learning and memory and focuses primarily on fear and stress related behavior. Dr. Fanselow is best known for his behavioral, neuropharmacological and anatomical characterization of contextual fear conditioning. One of his major early contributions to the field was the description of Pavlovian learning as an error-correcting circuit in which endogenous opioids perform an important error-calculating function. He has also explored the learning produced by experiences with drugs of abuse, particularly opioids. He uses rodent models with genetic, pharmacological, and surgical manipulations to pursue these questions. Dr. Fanselow also directs UCLA's Behavioral Testing Core where he provides instruction and support for investigators wishing to use rodent models.

Edmund Fantino received his B.A. in mathematics from Cornell University in 1961 and his Ph.D. in Psychology from Harvard University in 1964. After serving as Assistant Professor of Psychology at Yale University (1964–1967) he moved to the University of California, San Diego in 1967, where he has remained (now as Distinguished Professor of Psychology and the Neurosciences). His research has emphasized choice, irrational decisions, quantitative models of choice and foraging in humans and nonhumans, learning in educational contexts, and Comparative Psychology. He has served as Editor of the *Journal of the Experimental Analysis of Behavior* (1987–1991), on National Science Foundation and National Institute of Mental Health scientific advisory boards, and has promoted behavioral approaches at the U.S. House of Representatives. His books include *The Experimental analysis of behavior: A biological perspective*, and *Behaving well.*

William C. Follette is a Professor and member of the Clinical Faculty in the Department of Psychology at the University of Nevada, Reno. He received his Ph.D. in Psychology from the University of Washington. His interests include psychotherapy treatment development, outcome research design, program evaluation, functional analysis, assessment with clinical utility as a goal, and clinical behavior analysis.

He is particularly interested in the application of the principles of behavior analysis to outpatient adults with interpersonal deficits that result in diminished access to valued social reinforcement and that impede the individual in attaining his/her valued goals. Much of his intervention work focuses on helping people develop complex social repertoires through contingently shaped processes rather than rule-governed approaches often while studying Functional Analytic Psychotherapy as a vehicle to promote change. Dr. Follette has consulted with NIMH on the study of mechanisms of change, translational research, treatment dissemination, and programmatic research strategies.

Daniel A. Gottlieb received his B.S. in Psychology from Yale University, where he spent time in Allan Wagner's animal learning laboratory. He received his Ph.D. in Psychology from the University of Pennsylvania under the guidance of Robert Rescorla and spent two years as a postdoctoral researcher in C. R. Gallistel's laboratory at Rutgers University. He is now an Associate Professor of Psychology at Sweet Briar College, where he studies appetitive conditioning in rats and people.

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Steven R. Hursh (B.A., Wake Forest University, 1968; Ph.D., University of California, San Diego, 1972) is the President of the Institutes for Behavior Resources and Adjunct Professor of Behavioral Biology, Johns Hopkins University School of Medicine. Dr. Hursh has 40-years experience as a researcher and is author of more than 80 articles, book chapters, and books. He is a former Associate Editor of the *Journal of the Experimental Analysis of Behavior.* Dr. Hursh established Behavioral Economics as a major conceptual area. His research papers introduced into the behavioral vocabulary new concepts: open and closed economies, demand curves and elasticity, unit price, substitution and complementarity, P_{max}, O_{max}, and recently, exponential demand and essential value. His extensions to drug abuse and public policy have had a major impact on the research direction of programs supported by the National Institute of Health and other government agencies.

Kent Johnson is founder and Director of Morningside Academy a laboratory school for typical children and youth in Seattle. It investigates effective curricula and teaching methods, and has provided training to more than 125 schools throughout the world. Dr. Johnson's many publications about research-based curriculum and teaching methods include *The Morningside Model of generative instruction*, and *Response to intervention and precision teaching* with Dr. Elizabeth Street. More than 40,000 students and 1,000 teachers have implemented Morningside's Generative Instruction. Dr. Johnson received the Award for Public Service in Behavior Analysis from the Society for the Advancement of Behavior Analysis, the Anderson Award for Exemplary Contributions to Behavioral Education from the Cambridge Center for Behavioral Studies, the Award for Excellence in Evidence-based Education from the Wing Institute, the Allyn and Bacon Exemplary Program Award from the Council for Exceptional Children, and the Lindsley Lifetime Achievement Award in Precision Teaching from the Standard Celeration Society.

Alexander W. Kusnecov is Associate Professor of Psychology at Rutgers University. He obtained his Ph.D. in 1990 at the University of Newcastle, Australia, where he focused on the functional interface between the immune and nervous systems. Postdoctoral studies on Psychoneuroimmunology were conducted in the Department of Psychiatry, University of Rochester, New York. His research has continued to address different domains of neural-immune interactions. This has included behavioral conditioning of the immune system, as well as stressor effects on immune function. More recently, his research has addressed the neural, endocrine, and behavioral consequences of immunologic challenge with bacterial T cell superantigens, such as the staphylococcal enterotoxins.

Darnell Lattal received her Ph.D. in Clinical Psychology from West Virginia University. She is President of Aubrey Daniels International where she specializes in the design and implementation of behavioral-based business strategies to achieve core initiatives. Dr. Lattal is particularly effective in coaching individuals, from executives to line employees, to make sustained positive change, including corporate culture design and ethical practices. She has special expertise in the Psychology of Learning, designing sustainable yet rapid behavior change. Her publications include *Workplace ethics: Winning the integrity revolution*, coauthored with Ralph Clark; *Ethics at work*; *A good day's work: Sustaining ethical behavior and business results*; and *Reducing workplace stress through positive motivation strategies*, coauthored with Jun Ishida. She is currently coauthoring a book with Aubrey C. Daniels on how the science of behavior is influencing the workplace of the future.

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Margaret A. McDevitt is a Professor of Psychology at McDaniel College, a private college of the liberal arts and sciences located in Westminster, Maryland. She received her B.A. and M.S. in Psychology from California State University, Stanislaus, and her M.A. and Ph.D. in Experimental Psychology from the University of California, San Diego. She maintains a pigeon laboratory at McDaniel College where she studies basic learning processes with undergraduate students. Dr. McDevitt is particularly interested in conditioned reinforcement, and how the presence of stimuli affects the optimality of choice behavior. She lives near Baltimore with her husband and twin daughters.

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Raymond G. Miltenberger, Ph.D., BCBA-D, is the Director of the Applied Behavior Analysis Program at the University of South Florida. He is a Fellow and past President of the Association for Behavior Analysis International (ABAI). His research focuses on safety skills, behavior analysis in health, fitness, and sports, and staff training and management. He has published more than 185 journal articles and chapters and has written a behavior modification textbook, now in its 5th edition. Dr. Miltenberger has received a number of teaching and research awards including the American Psychological Association Division 25 Award for Distinguished Contributions to Applied Behavioral Research and the ABAI Outstanding Mentorship Award.

Eric S. Murphy is an Associate Professor in the Department of Psychology at the University of Alaska Anchorage (UAA). He received his B.A. from UAA and M.S. and Ph.D. in Experimental Psychology from Washington State University. Dr. Murphy has research and teaching interests in behavior analysis. He and his students are currently studying the variables that regulate reinforcer effectiveness in laboratory rats. Dr. Murphy has published in the *Journal of the Experimental Analysis of Behavior* and *Journal of Applied Behavior Analysis* and is the recipient of UAA's Faculty Exemplar Award for his work in enhancing undergraduate research opportunities.

Joel Myerson is Research Professor of Psychology at Washington University in St. Louis. He received his undergraduate degree from the University of Michigan, his Ph.D. from Arizona State University, and did postdoctoral research in Neurophysiology and Behavioral Biology at the University of Wisconsin, the University of California, Berkeley, and the California Institute of Technology. His areas of research concern age and individual differences in cognitive abilities as well as behavioral economics, and the development of formal theoretical models in these areas. His research has been published in *Science*, *Psychological Review*, *Psychological Bulletin*, *Journal of Experimental Psychology: General*, *Psychological Science*, and *Psychonomic Bulletin & Review*, as well as more specialized journals.

John A. Nevin, known as Tony, received his Ph.D. from Columbia University in 1963. He taught at Swarthmore College until 1968, then returned to Columbia where he served two years as Department Chair. In 1972, he moved to the University of New Hampshire, where he remained until retirement in 1995. He now lives with his wife Nora on the island of Martha's Vineyard, and maintains research collaborations with colleagues at other institutions with the support of the National Institutes of Health. His recent work focuses on applications of the behavioral momentum metaphor, which he developed over several decades with data from pigeons trained on multiple schedules of reinforcement, to the persistence of severe problem behavior in children with intellectual and developmental disabilities. The postretirement persistence of his work is itself an instance of momentum, based on the many reinforcers he has enjoyed throughout his life.

Amy Odum is a Professor in the Department of Psychology at Utah State University. Her research interests are in basic behavioral phenomena, such as response persistence, sensitivity to delayed outcomes, conditional discriminations, and environmental influences on drug effects. Her work has been funded by the National Institute on Drug Abuse and the National Institute of Mental Health. She completed a postdoctoral fellowship at the University of Vermont's Human Behavioral Pharmacology Laboratory after earning her Ph.D. and M.A. in Psychology, specializing in Behavior Analysis, from West Virginia University. She received a B.S. in Psychology from the University of Florida. Dr. Odum has been Associate Editor for the *Journal of the*

Experimental Analysis of Behavior and President of the Society for the Experimental Analysis of Behavior and Division 25 of the American Psychological Association.

David C. Palmer studied inter-response times and conditioned reinforcement in pigeons at the University of Massachusetts under John Donahoe in the early 1980s. Upon graduation, he took a job teaching statistics and behavior analysis at Smith College, where he remains today. His interests in behavior analysis are broad, but his main contributions have all been attempts to extend Skinner's interpretive accounts of human behavior, particularly in the domains of language, memory, problem solving, and private events. He remains convinced that behavioral principles offer an adequate foundation for interpreting such phenomena. Together with John Donahoe, he authored the text, *Learning and complex behavior*, which was an attempt to justify such optimism.

Linda A. Parker is a Canada Research Chair in Behavioral Neuroscience and Professor of Psychology at the University of Guelph, Ontario, Canada. She focuses her research on chemicals found naturally in the human body that mimic chemicals in marijuana, the endogenous cannabinoids (endocannabinoids). These chemicals were only discovered in the 1990s, yet they are now known to play a role not only in control of nausea and vomiting, but also in learning, memory, neuroprotection against stroke and cancer, appetite, reward and addiction. Linda Parker's program of research cuts across the traditional boundaries of Psychology, Pharmacology, and Neurobiology, contributing not only to understanding basic processes of learning, but also to how those processes impact on food selection, addiction, and gastrointestinal malaise.

Caitlin S. Peplinski is a graduate student at the University of Wisconsin–Milwaukee (UWM). She completed her bachelor's degree at Bradley University in 2007 with a major in Psychology. She was admitted to UWM's program in 2008 and is developing clinical research expertise in the assessment and treatment of severe behavior disorders.

Nancy M. Petry earned a Ph.D. from Harvard University in 1994. In 1996, she joined the faculty of the University of Connecticut Health Center, where she is Professor of Medicine in the Calhoun Cardiology Center. Dr. Petry conducts research on the treatment of behavioral disorders, ranging from substance use to gambling disorders, and she developed the prize reinforcement system that has been widely applied and disseminated in the context of treating substance use disorders. She has published over 250 articles, and her work is funded by the National Institutes of Health. She serves as a consultant and advisor for the National Institutes of Health and the Veterans Administration and was a member of the Substance Use and Related Disorders Workgroup for the DSM-5.

Karen Pryor is a behavioral biologist and writer. Trained at Cornell, the University of Hawaii, and Rutgers, she has focused on learning and behavior in areas ranging from human lactation to marine mammal ethology to autism. Never an academic (though an active guest lecturer), she served three years as a presidential appointee to the federal Marine Mammal Commission, and a decade as a consultant on dolphin behavior to the tuna fishing industry. Since 1992, Pryor and her associates have played an important role in popularizing marker-based training in dog training, in zoos, and in human care and education. In addition to technical publications, her popular books include *Nursing your baby* (on breast feeding), *Lads before the wind* (on dolphin training), *Don't shoot the dog!* (on positive training for humans), and *Reaching the animal mind* (on training and neuroscience). Pryor has three children and seven grandchildren, and presently lives in Boston.

Brittany C. Putnam is a graduate student at the University of Wisconsin–Milwaukee (UWM). She completed her bachelor's degree at Fairfield University in 2011 with a double major in Psychology and French. She was admitted to UWM's program in 2011 and is developing clinical research expertise in the assessment and treatment of severe behavior disorders.

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William A. Roberts has carried out research on a number of problems in animal cognition, including working memory, spatial memory, timing, numerical processing, concept learning, episodic-like memory, and metamemory since 1970. His work has been continuously supported by discovery grants from the Natural Sciences and Engineering Research Council of Canada, and he has published approximately 150 articles and book chapters. He has served as editor of the journal *Learning and Motivation* since 2000. His textbook, *Principles of animal cognition*, was published in 1998. Recent high-profile publications include an article, "Are animals stuck in time," in the *Psychological Bulletin*, two review articles on episodic-like memory in *Current Biology*, a research report on the temporal basis of episodic-like memory published in *Science*, a review of the comparative study of mental time travel in *Current Directions in Cognitive Science*, and a review of the study of metacognition in animals in *Comparative Cognition and Behavior Reviews.*

John M. Roll is Senior Vice-chancellor at the Washington State University (WSU) Health Sciences Campus located in Spokane, WA. He has faculty appointments in Nursing, Psychology, Neuroscience, Health Policy, and Administration as well as in the University of Washington School of Medicine. He is the Director of the WSU Program of Excellence in Addictions Research and Co-Director of the WSU Translational Addiction Research Center. Dr. Roll's work has focused on human behavioral pharmacology, the development and refinement of behavioral interventions for addiction and other psychiatric disorders, as well as technology transfer issues.

Sarah R. Sterlace received her undergraduate degree from University of California, Los Angeles (UCLA) and is a doctoral candidate in the Department of Psychology at UCLA with a concentration of Behavioral Neuroscience. Her primary research interests include molecular mechanisms that underlie fear learning and how fear memories are formed. Sarah has been investigating specific amygdalar nuclei and their individual contributions to fear acquisition, consolidation, and retrieval.

Elizabeth M. Street, who was a member of the faculty at Central Washington University (CWU) for 33 years, is a board-certified behavior analyst. A graduate of West Virginia University, Dr. Street was a doctoral student under Julie Vargas who first introduced her to Ogden Lindsley and Precision Teaching. Prior to taking a faculty position at CWU, Dr. Street held positions at the University of Illinois Child Behavior Laboratory under Sidney Bijou, at Help and Education for the Emotionally Disturbed School in Champaign, Illinois, at the Adolph Meyer Mental Health Center in Decatur, Illinois, and at the University of Wisconsin–LaCrosse. She has served for more than 30 years as a consultant and trainer for Morningside Academy in Seattle Washington where Precision Teaching is integral to its educational approach. Dr. Street's most recent book, coauthored with Kent Johnson, is *Response to intervention and precision teaching: Creating synergy in the classroom.*

Richard F. Thompson is Emeritus Keck Professor and University Professor of Psychology, Biological Sciences and Neuroscience at the University of Southern California (USC). His research concerns mammalian brain substrates and mechanisms of learning and memory. He has written or edited many books and published 450 research papers. After earning his M.S. and Ph.D. in Psychology and holding a post-doctoral fellowship in Neurophysiology, he joined the faculty at the University of Oregon Medical School and then at the University of California, Irvine, Harvard and Stanford Universities, before joining USC in 1987. Dr. Thompson was elected to the National Academy of Sciences, the American Academy of Arts and Sciences, and the American Philosophical Society. He has received many honors including the Distinguished Scientific Contribution Award from the American Psychological Association, the Lashley Award from the American Philosophical Society, and the Gold Medal for Lifetime Achievement in the Science of Psychology from the American Psychological Foundation.

Travis Thompson received his Ph.D. From the University of Minnesota and served as a Postdoctoral Fellow at the University of Maryland. He was a Visiting Fellow at the University of Cambridge before serving as an Assistant to Full Professor at the University of Minnesota. He then held faculty positions at Vanderbilt University and the University of Kansas Medical School before returning to the University of Minnesota where he is currently a Professor in the Department of Special Education. Dr. Thompson has received awards from Divisions 25 and 33 of the American Psychological Association (APA) and from the Society for the Advancement of Behavior Analysis. He has served as president of Divisions 28 and 33 of APA and on the Executive Council of the Association for Behavior Analysis International. He has given invited addresses in 47 states and 16 countries. He has published 30 books and 243 professional articles and chapters.

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Janet S. Twyman, Ph.D., BCBA, is a noted proponent of effective instruction and using technology to produce change. A career educator, she has been a preschool and elementary school teacher, a principal and administrator, and a university professor. Dr. Twyman has served on the boards of numerous organizations including the Cambridge Center for Behavioral Studies (chairing the Education Group) and PEER International (assisting township schools in Port Elizabeth, South Africa). In 2007–8, she served as President of the Association for Behavior Analysis International. Currently an Associate Professor of Pediatrics at the University of Massachusetts Medical School/Shriver Center, Dr. Twyman is also the Director of Innovation and Technology for the United States Department of Education's National Center on Innovations in Learning. She has published and presented internationally on evidence-based innovations in education and the systems that support them to produce meaningful difference in learners' lives.

Ariana Vanderveldt received her undergraduate degree from James Madison University and is an advanced graduate student in the Behavior, Brain, and Cognition program of the Department of Psychology at Washington University in St. Louis. Her primary research interests are in choice and decision-making. Ariana has been investigating how outcomes in choices are devalued when they are delayed in time and/or uncertain to occur, and how people make decisions that involve trade-offs among multiple attributes.

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Douglas A. Williams has maintained a nationally funded laboratory (Natural Sciences and Engineering Council of Canada) for some 20 years. Among his publications are more than a dozen articles in the prestigious *Journal of Experimental Psychology*, most coauthored with students from the mainly undergraduate University of Winnipeg. Many highly motivated undergraduates have made substantive contributions to his research program, later pursuing their own academic, research, or professional careers. He joined the faculty in 1991 after receiving a doctorate from the University of Minnesota under the guidance of J. Bruce Overmier and serving as a Killam Postdoctoral Fellow at Dalhousie University with Vincent M. LoLordo.

Preface

The *Wiley-Blackwell Handbook of Operant and Classical Conditioning* surveys the field of contemporary behavior analysis. The book is organized into four parts. Part I summarizes the basic principles, theories, and physiological substrates of classical conditioning. Habituation, a related fundamental form of learning, is also covered. Part II describes applications of classical conditioning. These applications include taste aversions, phobias, and immune system responses. Part III provides a review of the basic operant conditioning literature. Coverage ranges from traditional topics, such as basic operant principles and schedules of reinforcement, to the more contemporary topics of behavioral economics, behavioral momentum, and dynamic changes in reinforcer effectiveness. The final section of the book covers the growing field of applied behavior analysis. These applications range from intensive behavioral treatment for children with developmental disabilities to organizational behavior management to behavior analytic approaches to aging.

We chose to cover the topics of operant and classical conditioning in the same book because the basic principles of these two types of learning are similar. Therefore, an understanding of one type of conditioning can contribute to an understanding of the other type. As a result, the two types of learning are traditionally covered in a single volume. We chose to cover both basic principles and applications in the same book because we could not leave out either topic without ignoring a substantial part of the current literature on conditioning. In addition, we believe that applications cannot be properly understood without coverage of the principles on which they are based. Likewise, the understanding of basic principles is enriched and enhanced by a discussion of their applications.

There are many potential topics to cover in the broad areas of classical and operant conditioning. The choice of topics for this book is somewhat arbitrary. We have tried to select topics that are broad in coverage and, therefore, interesting to a relatively wide audience. This is particularly true in the section on applied behavior analysis in humans. With the exceptions of the chapters on autism and aging, we have tried to select topics that affect almost everyone, rather than concentrate on treatments for particular populations. We have also tried to select topics in which substantial research progress has been made since earlier conditioning handbooks were published and we gave priority to topics that were not covered recently in other books. Some topics were given a slightly lower priority because of less broad interest, slower recent research progress, or an ability to integrate these topics into other chapters. Our choices were also limited by our own prejudices and perspectives and by an occasional inability to find an appropriate and available author. We acknowledge that many worthy topics were omitted from this book.

The book is designed for advanced undergraduates and graduate students. It should provide a reference book for academicians, and professionals in behavior analysis including those who wish to conduct research in the area of conditioning, those who wish to use conditioning techniques as a baseline for understanding the effects of other variables (e.g., drugs), and those who wish to use conditioning techniques to either understand or treat challenging behaviors.

The chapters contained within this volume provide a summary of the chosen subfields within behavior analysis. Each author was chosen specifically for his or her expertise. Without the authors' dedication to this project, this book would not be possible. We are sincerely indebted to each contributor. We would also like to thank the dedicated staff at Wiley-Blackwell. Andrew Peart provided much-needed support and advice during the early stages of the project. We are also grateful to Karen Shield and Rosemary Morlin for their help with clearing copyright permissions and copyediting the book.

Frances K. McSweeney and Eric S. Murphy
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Part I

Basic Classical Conditioning

1

Principles of Pavlovian Conditioning

Description, Content, Function

Daniel A. Gottlieb and Elizabeth L. Begej

Although both early human memory researchers and behaviorists studied processes that today would be considered Pavlovian, Ivan Pavlov is credited with discovering classical conditioning and first officially describing the process to an English-speaking audience with the publication of *Conditioned reflexes* in 1927. Pavlov's systematic investigation of Pavlovian conditioning uncovered most of the primary phenomena, and his sharp and nuanced discussions are still relevant today.

Gottlieb (2011) defined Pavlovian, or classical, conditioning as the "adjustments organisms make in response to observing the temporal relations among environmental or proprioceptive stimuli." The most well-known form involves pairing a neutral conditioned stimulus (CS) with a biologically relevant unconditioned stimulus (US) that automatically elicits an unconditioned response (UR), leading the CS to elicit a conditioned response (CR) qualitatively similar to the UR. Pavlov's first reported example used dogs as subjects, a metronome CS, food as the US, and salivation as the UR and CR (Pavlov, 1927, p. 26).

Pavlovian conditioning is most clearly defined and constrained by its method, which involves maintaining strict control over the presentation of stimuli. There appear to be few clear principles that distinguish Pavlovian conditioning from other forms of associative learning, such as instrumental learning and human associative memory, and we agree with Rescorla and Solomon (1967)'s conclusion the Pavlovian conditioning is most distinct in how determined the form of the learned response is by the choice of US. Pavlovian responding is also characteristically resistant to instrumental contingencies. For example, it is difficult to prevent a pigeon from pecking (CR) at a discrete key light (CS) paired with food (US), even if pecking prevents the delivery of food (Williams & Williams, 1969).

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Overview

Basic Excitatory Phenomena

Acquisition is the primary phenomenon of Pavlovian conditioning and refers to the growth in conditioned responding resulting from pairing a CS and US over time (Pavlov, 1927, p. 26). A CS that produces conditioned responding is sometimes referred to as an excitor. An example of an excitor is a brief tone that, due to repeated pairings with an air puff to the eye, elicits anticipatory eyeblinking.

An animal that has learned to blink to a tone may also blink when presented with a novel auditory stimulus. The magnitude of this generalized responding is a function of the similarity of the new stimulus to the originally trained CS (Pavlov, 1927, p. 111). Generalization functions can be modified by discrimination learning, in which some stimuli are reinforced while others are nonreinforced. For example, the generalized responding from a tone to a burst of white noise can be reduced by interspersing presentations of the noise alone.

A tone paired with an air puff to the eye gains more than the ability to elicit anticipatory blinking. It also develops the ability to serve as a conditioned reinforcer for another, second-order, CS (Pavlov, 1927, p. 33). Second-order conditioning tends to lead to lower levels of responding than does first-order conditioning. Thus, a light paired with a tone excitor will likely elicit less conditioned eyeblinking than will the tone itself. Conditioned reinforcers are contrasted with primary reinforcers that do not need prior training to be able to establish conditioned responding. Unlike in instrumental conditioning, Pavlovian reinforcers refer to stimuli that may be appetitive or aversive.

Basic Inhibitory Phenomena

Inhibitory phenomena are those that manifest in opposition to conditioned responding. When stimuli both reduce responding to simultaneously presented excitors and are slow to become excitors themselves, as compared to neutral stimuli, they are called inhibitors (Rescorla, 1969a). This type of inhibition is sometimes referred to as operational inhibition. It is contrasted with the theoretical inhibition that is used as an explanation for transient decreases in excitatory responding.

Extinction refers to the loss in conditioned responding that occurs when an excitor is subsequently presented in a manner that breaks the CS-US relationship (Pavlov, 1927, p. 49). For example, our tone excitor will stop eliciting conditioned eye-blinks if it is repeatedly presented alone. Although extinction is explained by appeal to inhibitory mechanisms, extinguished stimuli do not typically become operational inhibitors (Rescorla, 1969a).

Suppression of responding may also be observed when a nonreinforced stimulus is interspersed among the reinforced trials of another CS and a US. For example, if noise alone presentations are interspersed among tone-air puff pairings, generalized responding to the noise will be reduced. The suppression of responding observed in a discrimination procedure is referred to as differential inhibition. Unlike extinguished stimuli, differentially conditioned stimuli may become operational inhibitors (Pavlov, 1927, p. 120).

A particularly powerful form of differential inhibition results from a conditioned inhibition procedure in which a stimulus is nonreinforced in the presence of an excitor that is reinforced when presented alone. For example, if our tone signals an air puff except when it is presented together with a light, the light will become a conditioned inhibitor capable of passing the operational tests for inhibition (Pavlov, 1927, p. 68).

Perhaps it is not surprising that with extended training, organisms may come to withhold responding to a CS until closer to the time of the US. The decrease in responding to early parts of a CS that may result from extended training is referred to as inhibition of delay (Pavlov, 1927, p. 88).

Basic Framework

Early theorists most often adopted a contiguity view of learning, in which the pairing of stimuli in time and space was the necessary and sufficient condition for generating conditioned responding. Although Hull (1943) expanded on this view in arguing that drive reduction was also necessary for learning, it is his other contributions that have made him central to contemporary understandings of Pavlovian processes.

Hull (1943) adopted the view of Pavlovian conditioning as an associative process by which the magnitude of the association determined the magnitude of conditioned responding. He presented a simple mathematical learning rule that specified the change in associative (habit) strength that resulted from the pairing of a CS and a US. The vast majority of subsequent quantitative models developed within the associative framework contain Hull's simple learning algorithm (Mackintosh, 1975; Pearce, 1987; Rescorla & Wagner, 1972; Wagner, 1981).

Hull (1943) helped to cement a view of Pavlovian conditioning as an incremental trial-based process involving changes in the associative strength between stimuli. The parameters of his model are what were originally thought to be the determinants of Pavlovian learning. Primary was the number of trials. Secondary included three durations related to the CS-US interval: the length of the CS, the temporal gap between the CS and US, and the extension of the CS past the US; as well as two salience parameters, one for the CS and one for the US.

Hull's Choices

CS-US Interval

Delay Conditioning. Most demonstrations of acquisition use a delay conditioning procedure where CS offset coincides with US onset. As such, CS duration is the only determinant of the CS-US interval in delay conditioning. There appear to be two conflicting ideas related to effects of CS duration. The first is that there is an optimal CS-US interval that is highly procedure-dependent. For skeletal muscle CRs, like eyeblink conditioning, the optimal CS-US interval is often a fraction of a second (Gormezano & Kehoe, 1981), but for other types of CRs, such as sign-tracking and conditioned fear, the optimal interval may be multiple seconds (Gibbon, Baldock, Locurto, Gold, & Terrace, 1977; Yeo, 1974).

That there is an optimal CS-US interval conflicts with the other main idea about CS duration, that shortening it promotes acquisition (Lattal, 1999). This conflict is likely a result of optimal durations being at the low end of the range of durations that can establish conditioned responding. What appears most relevant is that certain procedures allow for conditioning with CS-US intervals much longer than others. In fear conditioning, CS durations of several minutes can be effective (Kamin, 1965), and in conditioned taste aversion, CS-US trace intervals of up to 24 hours can establish conditioned aversions (Etscorn & Stephens, 1973).

Trace Conditioning. When the CS terminates prior to US onset, acquisition of conditioned responding may be strongly impaired (Ellison, 1964). This procedure is known as trace conditioning, referring to one explanation for the conditioned responding that does occur: A memory trace of the CS is contiguously paired with the US. Although a gap between CS offset and US onset impairs conditioned responding, the impairment does not necessarily reflect a failure to learn. Trace conditioning can lead a CS to become inhibitory (LoLordo & Fairliss, 1985). It also may lead to increasing levels of responding during the time between CS offset and US onset (Marlin, 1981).

Simultaneous Conditioning. Early research suggested that simultaneous CS-US presentation did not lead to conditioned responding (Kimble, 1961), but it is clear that in many cases it does (Heth & Rescorla, 1973). Simultaneous conditioning may lead to different forms of learning than does forward conditioning. For example, in flavor conditioning, simultaneous, but not delay, conditioning prevents the reacquisition of an extinguished preference (Higgins & Rescorla, 2004).

Backward Conditioning. Backward conditioning refers to presenting the US prior to presenting the CS. Typically, US offset and CS onset coincide. After a small number of trials, it is not uncommon to observe excitatory conditioned responding, but after further trials, the responding diminishes and the CS may become an inhibitor (Heth, 1976). One complexity is that a backward CS may pass an operational test for inhibition while at the same time establishing excitatory second-order conditioning to another CS (Barnet & Miller, 1996). Romaniuk and Williams (2000) provided an explanation for this by demonstrating that the initial 3 s of a 30 s backwards CS was excitatory while the remaining 27 s was inhibitory. Adding a 3 s gap between US offset and CS onset eliminated excitatory responding, strengthened inhibition, and prevented second-order conditioning.

Stimulus Intensity

US Magnitude. Some argue that acquisition of conditioned responding should be broken down into components that include the point of acquisition and the asymptotic magnitude of responding (Gallistel, Fairhurst, & Gibbon, 2004). In general, increasing US intensity or number tends to increase the magnitude of conditioned responding (Mackintosh, 1974, pp. 70–71); however, although Morris and Bouton (2006) detected effects of US magnitude on the point of acquisition in aversive and appetitive procedures with rats, how strongly US magnitude influences the point of acquisition is still not clear. Unlike US intensity, the effects of increasing US duration are not consistent across procedures (Mackintosh, 1974).