

TABLE OF CONTENTS

- List of Contributors

Section 1: Introduction

Chapter 1. Beyond the Cellular Alphabet of Learning and Memory in Invertebrates

Introduction

Beyond the Cellular Alphabet: Circuit and Network Levels of Analysis, the Necessary Step

Do Invertebrates have Cognitive Abilities?

References

Section 2: Concepts of Invertebrate Comparative Cognition

Chapter 2. Action Selection: The Brain as a Behavioral Organizer

Introduction

Behavioral Modules

Outcome Expectation

The Active Brain

Action Selection

Conclusions

Acknowledgments

References

Chapter 3. Cognitive Components of Insect Behavior

Introduction

Acting Upon the Environment: Exploration, Instrumental Learning, and Observational Learning

Expectation

Generalization, Categorization, and Concept Learning

Memory Processing

Insect Intelligence and Brain Structure

Miniature Brains

Conclusion

References

Chapter 4. Exploring Brain Connectivity in Insect Model Systems of Learning and Memory: Neuroanatomy Revisited

Introduction

Insect Brains are Small

Methods of Analyzing Insect Microcircuits

Discussion and Outlook

References

Chapter 5. 'Decision Making' in Larval *Drosophila*

Introduction

Architecture of the Chemobehavioral System

A Working Hypothesis of Memory Trace Formation

The Decision to Behaviorally Express a Memory Trace—or Not

Aspects of Decision Making

Conclusion

Acknowledgments

References

Section 3: Developments in Methodology

Chapter 6. Optophysiological Approaches to Learning and Memory in *Drosophila melanogaster*

Introduction: Strategies to Determine Neuronal Substrates Underlying Learning and Memory

Disruptive Alterations: Ablation, Mutation, and Block of Synaptic Transmission

Detectability: Optical Imaging Using DNA-Encoded Fluorescence Probes

Mimicry: Optogenetic and Thermogenetic Activation of Neurons

Conclusions

Acknowledgment

References

Chapter 7. Computational Analyses of Learning Networks

Introduction

Olfactory Learning in Insects

Nonassociative and Associative Learning in Gastropods

Conclusions

Acknowledgment

References

Chapter 8. Issues in Invertebrate Learning Raised by Robot Models

Introduction

Robot Models of Invertebrate Learning

What is Associated with What in Classical Conditioning?

Conclusion

Acknowledgments

References

Section 4: Mechanisms from the Most Important Systems

Chapter 9. Mechanosensory Learning and Memory in *Caenorhabditis elegans*

Introduction to *Caenorhabditis Elegans* Learning and Memory

Characteristics of Short-Term Tap Habituation

Development of Tap Habituation

Circuitry Underlying Tap Habituation

Neurotransmitters Involved in Tap Habituation

Locus of Plasticity in Tap Habituation

Genes that Play a Role in Tap Habituation

Long-Term Memory for Tap Habituation

Context: Short-Term and Long-Term Memory

Conclusions

References

Chapter 10. Molecular and Cellular Circuits Underlying *Caenorhabditis elegans* Olfactory Plasticity

Caenorhabditis Elegans Olfactory System

Caenorhabditis Elegans Olfactory Plasticity

Summary

Acknowledgments

References

Chapter 11. Thermosensory Learning in *Caenorhabditis elegans*

Caenorhabditis Elegans Neuroscience

Behavioral Plasticity in *C. Elegans*

Thermotaxis in *C. Elegans*

Neural Circuit for Thermotaxis

Thermosensory Signaling

AFD Thermosensory Neurons Memorize Cultivation Temperature: the Sensory Neuron Acts as a Memory Device

Associative Learning between Temperature and Food

Regulation of Associative Learning by Insulin and Monoamine Signaling

Information Flow from AFD and AWC to AIY

RIA Interneuron as an Integrator and Locomotion Controller

Conclusion and Perspective

Acknowledgments

References

Chapter 12. Age-Dependent Modulation of Learning and Memory in *Caenorhabditis elegans*

Introduction

Classification of Learning and Memory

Reduced Plasticity but Well-Retained 'Old Memory'

Two Phases of AMI

Aging-Related Changes in Associative Learning and Memory

Endocrine Disturbance as a Cause of Early AMI

Neural Regulation of Memory and AMI

Midlife Crisis Theory and Epigenetic Changes

Perspectives

References

Chapter 13. Salt Chemotaxis Learning in *Caenorhabditis elegans*

Salt Chemotaxis in *Caenorhabditis Elegans*

Salt Chemotaxis Learning: The Behavior

The Role of ASE Neurons in Salt Chemotaxis Learning

The Insulin/Phosphatidylinositol 3-Kinase Pathway

The Gq/Diacylglycerol/Protein Kinase C Pathway

Other Genes Acting in ASER

The EGL-8/Diacylglycerol/Protein Kinase D Pathway Acting in ASEL

Involvement of Other Sensory Neurons

Roles of Interneurons

Changes in Neuronal Activities Caused by Learning

How is the Starvation Signal Transmitted?

Molecular Pathways for memory retention

Long-Term Memory

Experience-Dependent Salt Chemotaxis in Fed Animals

Conclusion

References

Chapter 14. A Systems Analysis of Neural Networks Underlying Gastropod Learning and Memory

Introduction

Behavior and Model Networks

The Complexity of Gastropod Learning

Synaptic Mechanisms for Learning

Nonsynaptic Cellular Mechanisms for learning

Discussion and Conclusions

Acknowledgments

References

Chapter 15. Comparison of Operant and Classical Conditioning of Feeding Behavior in *Aplysia*

Introduction

Feeding Behavior in *Aplysia* and its Underlying Neural Circuit

Feeding Behavior is Modified by Associative Learning

Cellular Analysis of Appetitive Classical and Appetitive Operant Conditioning of Feeding

Comparison of the Molecular Mechanisms of Operant and Classical Conditioning

Conclusions

Acknowledgments

References

Chapter 16. Mechanisms of Short-Term and Intermediate-Term Memory in *Aplysia*

Introduction

Simple Forms of Learning in *Aplysia*

Short-Term Plasticity

The Relationship Between Short- and Long-Term Plasticity, and the Discovery of Intermediate-Term Plasticity

Mechanisms of Induction, Maintenance, and Expression of Intermediate-Term Facilitation

Pre- and Postsynaptic Mechanisms of Intermediate-Term Plasticity

Spontaneous Transmitter Release is Critical for the Induction of Intermediate- and Long-Term Facilitation

Spontaneous Transmitter Release from the Presynaptic Neuron Recruits Postsynaptic Mechanisms of Intermediate- and Long-Term Facilitation

Conclusions

Acknowledgments

References

Chapter 17. Synaptic Mechanisms of Induction and Maintenance of Long-Term Sensitization Memory in *Aplysia*

Introduction

Long-Term Sensitization in *Aplysia*: Mechanisms of Induction

Maintenance of LTS Memory in *Aplysia*

Summary

Acknowledgments

References

Chapter 18. Roles of Protein Kinase C and Protein Kinase M in *Aplysia* Learning

Introduction

The PKC Family

Isoform-Specific Roles of PKCs during Distinct Learning Paradigms

Interaction of PKCs with Other Signal Transduction Pathways

Conclusion

Acknowledgments

References

Chapter 19. Multisite Cellular and Synaptic Mechanisms in *Hermissenda*
Pavlovian Conditioning

Introduction

Pavlovian Conditioning and the CR Complex

Neural Network

Long-Term Memory Following Multitrial Conditioning

Cellular and Molecular Mechanisms Underlying Short-, Intermediate-, and
Long-Term Memory Formation

One-Trial Conditioning

Second Messengers

Long-Term Memory Depends on Translation and Transcription

Proteins Regulated by Pavlovian Conditioning: Proteomic Analyses

Mechanisms of CS–US Associations in Sensory Neurons

Summary

References

Chapter 20. Molecular and Cellular Mechanisms of Classical Conditioning in
the Feeding System of *Lymnaea*

Introduction

Molecular Mechanisms of Classical Conditioning in the Feeding System of
Lymnaea

Cellular Mechanisms of Classical Conditioning in the Feeding System of *Lymnaea*

Conclusions

References

Chapter 21. Operant Conditioning of Respiration in *Lymnaea*: The Environmental Context

Introduction

Aerial Respiratory Behavior

Operant Conditioning of Aerial Respiratory Behavior

Ecologically Relevant Stressors and LTM Formation

What is Stressful for a Snail?

Resource Restriction

Social Stress

Thermal Stress

Anthropogenic Stress

Interaction between Stressors

Population Differences

Conclusions

References

Chapter 22. Associative Memory Mechanisms in Terrestrial Slugs and Snails

Introduction

Learning Solutions to Lifestyle Challenges by Terrestrial Gastropods

Complexity of Odor Conditioning

Neurogenesis May Contribute to Olfactory Learning

Procerebrum as an Olfactory Learning Center

Progress with *Limax* Odor Learning

Learning of Tentacle Position

Conclusions

References

Chapter 23. Observational and Other Types of Learning in *Octopus*

Introduction

Complexity versus Simplicity: Examples from Octopuses

Smart versus Stupid: Learning and Other Forms of Behavioral Plasticity

Learning from Others in Octopuses: Experimental Evidence

Why Should Octopus Possess Social Learning Skills?

Conclusions

Acknowledgments

References

Chapter 24. The Neurophysiological Basis of Learning and Memory in Advanced Invertebrates: The Octopus and the Cuttlefish

Introduction

The Cephalopod Nervous System

Anatomy of the Vertical Lobe System

Neurophysiology of Sfl Input to the Octopus Vertical Lobe

Neuronal Output from the Vertical Lobes of Octopus and Cuttlefish Demonstrates Activity-Dependent Long-Term Potentiation

Synaptic Plasticity in the Vertical Lobes of Octopus and Cuttlefish

What do the Vertical Lobes of Octopus and Cuttlefish Compute?

Mechanism of LTP Induction in the Octopus Vertical Lobe

Neuromodulation in the Vertical Lobe

Are the Octopus Vertical Lobe and its LTP Involved in Behavioral Learning and Memory?

A System Model for Octopus Learning and Memory

Conclusion

Acknowledgments

References

Chapter 25. Learning, Memory, and Brain Plasticity in Cuttlefish (*Sepia officinalis*)

Introduction

The Cuttlefish Brain

Brain and Behavioral Plasticity in Adults

Developmental Perspectives

Conclusion

References

Chapter 26. A Multidisciplinary Approach to Learning and Memory in the Crab *Neohelice (Chasmagnathus) granulata*

Introduction: Crustaceans as Model Systems in Neurobiology

Learning and Memory in Crustaceans

The Crab *Neohelice*: Habitat and Habits

Crab Learning in the Laboratory

Context-Signal Memory

Massed and Spaced Training Render Two Different Kinds of Memory

Anatomical Description of Brain Regions Involved in Crab's Visual Memory

In Vivo Physiological Characterization of Brain Interneurons

Characterization of the LG Neurons and their Role in the Crab Escape Response

LG Neurons and their Role in Visual Learning and Memory

Pharmacological and Molecular Characterization of CSM Formation and Processing

Role of Protein Kinase a in Memory Consolidation

Mitogen-Activated Protein Kinases in CSM

Rel/NF- κ B, a Key Transcription Factor in Consolidation of CSM

Epigenetic Mechanisms in CSM Formation

CSM Reconsolidation and Extinction: A Cornerstone in the Study of Memory Reprocessing

Conclusion

Acknowledgment

References

Chapter 27. *Drosophila* Memory Research through Four Eras: Genetic, Molecular Biology, Neuroanatomy, and Systems Neuroscience

Introduction

The Genetics of *Drosophila* Learning

Drosophila Learning

The Olfactory Nervous System

Neural Circuits underlying learning and memory

Subcellular Signaling Dynamics

Memory Traces

Outlook

References

Chapter 28. Visual Learning and Decision Making in *Drosophila melanogaster*

Introduction

Drosophila Vision

Classical and Operant Conditioning

Invariant Recognition and Memory Traces

Feature Extraction and Context Generalization

Multisensory Perception and Cross-Modal Memory

Spatial Learning and Working Memory

Attention-Like Fixation Behavior and Visual Selective Attention

Decision Making

Perspectives

Acknowledgments

References

Chapter 29. In Search of the Engram in the Honeybee Brain

The Concept of the Engram

The Olfactory Learning Paradigm

The Olfactory Pathway in the Bee Brain and Potential Locations of the Engram

The Antennal Lobe

Intrinsic Neurons of the Mushroom Body: Kenyon Cells

Extrinsic Neurons of the Mushroom Body

The Lateral Horn

Memory Traces in the Reward Pathway

The Distributed Nature of the Engram

Conclusion

References

Chapter 30. Neural Correlates of Olfactory Learning in the Primary Olfactory Center of the Honeybee Brain: The Antennal Lobe

Introduction

Studied Forms of Olfactory Learning in Honeybees

The Olfactory System

The Search for Experience-Induced Plasticity in the Antennal Lobe

Where Do We Go from Here? The Multifactorial Quality of the Search for Neural Plasticity

Acknowledgments

References

Chapter 31. Memory Phases and Signaling Cascades in Honeybees

Appetitive Olfactory Learning in Honeybees: Behavior and Neuronal Circuitry

Reward and Odor Stimuli Induce Fast and Transient Activation of the cAMP- and Ca²⁺-Dependent Signaling Cascades in the Antennal Lobes

The Link between Training Parameters and Memory Formation: The Specific Role of Second Messenger-Regulated Signaling Cascades

Satiation Affects Formation of Appetitive Memory via Molecular Processes during Conditioning

Midterm Memory Requires the Interaction of a Ca²⁺-Regulated Protease and Protein Kinase C

Mushroom Body Glutamate Transmission is Implicated in Memory Formation

Parallel Signaling Processes in the ALs and the MBs Contribute to Memory Formation

Acknowledgments

References

Chapter 32. Pheromones Acting as Social Signals Modulate Learning in Honeybees

Introduction

Pheromones and their Roles

Pheromone Modulation of Learning Behavior

Coincidental or Adaptive?

Modes of Action

A Focus for Future Studies

References

Chapter 33. Extinction Learning and Memory Formation in the Honeybee

Extinction Resembles an Animal's Adaptation to a Fluctuating Environment

Classical Conditioning in Harnessed Honeybees

Spontaneous Recovery from Extinction Demonstrates the Existence of Two Memories

Reinstatement of the Extinguished Memory is Context Dependent

Extinction of a Consolidated Long-Term Memory

Consolidating Extinction Memory

Extinction Memory Formation Depends on Reward Learning

Reconsolidation of Reward Memory

Protein Degradation Constrains the Reward Memory

Epigenetic Mechanisms Impact on Memory Formation and the Resistance to Extinction

Extinction in Vertebrates and Honeybees: Conserved Behavior, Conserved Molecular Mechanisms, but Different Brains?

Conclusion

References

Chapter 34. Glutamate Neurotransmission and Appetitive Olfactory Conditioning in the Honeybee

Introduction

Glutamate and Components of the Glutamate Neurotransmission in the Honeybee Nervous System

Architecture of the Glutamatergic Neurotransmission

Glutamatergic Neurotransmission is Important for Learning and Memory

Conclusion

References

Chapter 35. Cellular Mechanisms of Neuronal Plasticity in the Honeybee Brain

Introduction

Cellular Physiology of Membrane Excitability

Synaptic Transmitters and their Receptors

Cell Physiological Events Underlying Olfactory Learning

Conclusions

References

Chapter 36. Behavioral and Neural Analyses of Punishment Learning in Honeybees

Introduction

Olfactory Conditioning of the Sting Extension Reflex

Olfactory Conditioning of Ser is a True Case of Aversive Learning

Olfactory Conditioning of Ser Leads to the Formation of Long-Term Memories

The Neural Basis of Aversive Learning

Dopaminergic Neurons in the Bee Brain

Modularity of Reward and Punishment Systems in Honeybees

Conclusion

References

Chapter 37. Brain Aging and Performance Plasticity in Honeybees

Social Caste, Social Environment, and Flexible Life Histories in the Honeybee

Behavioral Senescence in Honeybees

Heterogeneity of Behavioral Aging

Aging Interventions

Negligible Senescence

Underpinnings of Plastic Brain Aging

Immune Defenses and Aging

Proteome, Aging, and the Reversal of Aging Symptoms

Application-Oriented Research: Screening for Treatments that may Extend Life Span and Improve Health

Synthesis

Acknowledgments

References

Chapter 38. Learning and Recognition of Identity in Ants

Is Learning Involved in the Formation of the Nestmate Recognition Template?

When Learning and Memory are Indispensable

Tools to Study Olfactory Learning and Memory in Ants

Acknowledgments

References

Chapter 39. Bounded Plasticity in the Desert Ant's Navigational Tool Kit

The Major Transition in the Ant's Adult Lifetime

Path Integration

Interplay between Path Integration and Landmark Guidance Routines

Plasticity of the Adult Ant's Brain

Acknowledgments

References

Chapter 40. Learning and Decision Making in a Social Context

Introduction

Social Learning through Teaching

Colony-Level Learning

Conclusion

References

Chapter 41. Olfactory and Visual Learning in Cockroaches and Crickets

Introduction

Olfactory and Visual Learning in Crickets

Visual and Olfactory Learning in Cockroaches

Conclusion and Future Perspective

References

Chapter 42. Individual Recognition and the Evolution of Learning and Memory in *Polistes* Paper Wasps

Introduction

Evolution of Individual Recognition

Individual Recognition and Social Memory

Detailed Methods for Training Wasps

Specialized versus Generalized Visual Learning

References

Index.