Springer Handbook of Auditory Research

Micheal L. Dent
Richard R. Fay
Arthur N. Popper *Editors*

Rodent Bioacoustics

ASA PRESS

Springer

Springer Handbook of Auditory Research

Volume 67

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ISSN 0947-2657 ISSN 2197-1897 (electronic)
Springer Handbook of Auditory Research
ISBN 978-3-319-92494-6 ISBN 978-3-319-92495-3 (eBook)
https://doi.org/10.1007/978-3-319-92495-3

Library of Congress Control Number: 2018951414

This Springer imprint is published by the registered company Springer Nature Switzerland AG
The registered company address is: Gewerbestrasse 11, 6330 Cham, Switzerland

This volume is dedicated to Dr. Robert J. Dooling. While Bob's research has focused on birds, his scholarly approach and important findings have impacted all modern comparative research on vertebrate hearing. In addition to being a superlative scholar, Bob continues to be an exceptional mentor and a valued collaborator and friend to all of the editors of this volume. (Photo credit: John T. Consoli/University of Maryland).

Acoustical Society of America

The purpose of the Acoustical Society of America (ASA; www.acousticalsociety.org) is to generate, disseminate, and promote the knowledge of acoustics. The ASA is recognized as the world's premier international scientific society in acoustics, and counts among its more than 7000 members, professionals in the fields of bioacoustics, engineering, architecture, speech, music, oceanography, signal processing, sound and vibration, and noise control.

Since its first meeting in 1929, the ASA has enjoyed a healthy growth in membership and in stature. The present membership of approximately 7000 includes leaders in acoustics in the United States of America and around the world. The ASA has attracted members from various fields related to sound, including engineering, physics, oceanography, life sciences, noise and noise control, architectural acoustics; psychological and physiological acoustics; applied acoustics; music and musical instruments; speech communication; ultrasonics, radiation, and scattering; mechanical vibrations and shock; underwater sound; aeroacoustics; macrosonics; acoustical signal processing; bioacoustics; and many more topics.

To assure adequate attention to these separate fields and to new ones that may develop, the Society establishes technical committees and technical groups charged with keeping abreast of developments and needs of the membership in their specialized fields. This diversity and the opportunity it provides for interchange of knowledge and points of view has become one of the strengths of the Society.

The ASA's publishing program has historically included *The Journal of the Acoustical Society of America, JASA-Express Letters, Proceedings of Meetings on Acoustics*, the magazine *Acoustics Today*, and various books authored by its members across the many topical areas of acoustics. In addition, ASA members are involved in the development of acoustical standards concerned with terminology, measurement procedures, and criteria for determining the effects of noise and vibration.

Series Preface

Springer Handbook of Auditory Research

The following preface is the one that we published back in 1992. As anyone reading the original preface, or the many users of the series, will note, we have far exceeded our original expectation of eight volumes. Indeed, with books published to date and those in the pipeline, we are now set for over 65 volumes in SHAR, and we are still open to new and exciting ideas for additional books.

We are very proud that there seems to be consensus, at least among our friends and colleagues, that SHAR has become an important and influential part of the auditory literature. While we have worked hard to develop and maintain the quality and value of SHAR, the real value of the books is very much because of the numerous authors who have given their time to write outstanding chapters and to our many co-editors who have provided the intellectual leadership to the individual volumes. We have worked with a remarkable and wonderful group of people, many of whom have become great personal friends of both of us. We also continue to work with a spectacular group of editors at Springer. Indeed, several of our past editors have moved on in the publishing world to become senior executives. To our delight, this includes the current president of Springer US, Dr. William Curtis.

But the truth is that the series would and could not be possible without the support of our families, and we want to take this opportunity to dedicate all of the SHAR books, past and future, to them. Our wives, Catherine Fay and Helen Popper, and our children, Michelle Popper Levit, Melissa Popper Levinsohn, Christian Fay, and Amanda Fay Sierra, have been immensely patient as we developed and worked on this series. We thank them and state, without doubt, that this series could not have happened without them. We also dedicate the future of SHAR to our next generation of (potential) auditory researchers – our grandchildren – Ethan and Sophie Levinsohn, Emma Levit, and Nathaniel, Evan, and Stella Fay.

Preface 1992

The Springer Handbook of Auditory Research presents a series of comprehensive and synthetic reviews of the fundamental topics in modern auditory research. The volumes are aimed at all individuals with interests in hearing research, including advanced graduate students, post-doctoral researchers, and clinical investigators. The volumes are intended to introduce new investigators to important aspects of hearing science and to help established investigators to better understand the fundamental theories and data in fields of hearing that they may not normally follow closely.

Each volume presents a particular topic comprehensively, and each serves as a synthetic overview and guide to the literature. As such, the chapters present neither exhaustive data reviews nor original research that has not yet appeared in peer-reviewed journals. The volumes focus on topics that have developed a solid data and conceptual foundation rather than on those for which a literature is only beginning to develop. New research areas will be covered on a timely basis in the series as they begin to mature.

Each volume in the series consists of a few substantial chapters on a particular topic. In some cases, the topics will be ones of traditional interest for which there is a substantial body of data and theory, such as auditory neuroanatomy (Vol. 1) and neurophysiology (Vol. 2). Other volumes in the series deal with topics that have begun to mature more recently, such as development, plasticity, and computational models of neural processing. In many cases, the series editors are joined by a co-editor having special expertise in the topic of the volume.

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Volume Preface

Rodents are one of the largest of all mammalian taxa, and a number of rodent species are among the most important model systems for biomedical research, including the study of hearing. Indeed, rodents have been featured “subjects” in many volumes in the Springer Handbook of Auditory Research (SHAR) series because so much of what we know about issues covered in the various volumes was gained through the use of rodents as model systems. Thus, since rodents are so important for what we know about hearing, it became clear that bringing together an overview of what is known (and not known) about rodent bioacoustics would be of considerable value to the auditory (and bioacoustic) research community. Most rodent research has focused on just a few species (mice, rats, and, to a lesser degree, chinchilla) among the 2000 rodent species. This volume, however, includes a wealth of bioacoustic data on less frequently used rodent species and provides the basis for a broader understanding of rodents. Chapters in this volume describe rodent bioacoustics from several different approaches.

Chapter 1 by Micheal L. Dent provides an overview of the wide range of rodent taxa as well as a summary of the contents of the book. In Chap. 2, Kazao Okanoya and Laurel A. Screven describe acoustic signals in air in both laboratory-raised and wild rodents in both the laboratory and the field, making this one of the most diverse chapters in terms of the numbers of rodent species studied. This is followed by a consideration of acoustic communication in subterranean rodents in Chap. 3 by Cristian Schleich and Gabriel Francescoli, who provide a more neuroethological perspective than other chapters in this volume. Chapter 4 by Micheal L. Dent, Laurel A. Screven, and Anastasiya Kobrina summarizes behavioral and physiological auditory acuity of all rodent species tested to date. An important part of hearing is binaural processing and sound localization, and these issues are considered in Chap. 5 by Amanda M. Lauer, James H. Engel, Jr., and Katrina Schrode.

The chapters on vocalizations and hearing are followed by a series of more mechanistic chapters. In Chap. 6, M. Fabiana Kubke and J. Martin Wild discuss the anatomy of vocalization and hearing. This is followed by a discussion of rodent models for genetic and age-related hearing issues in Chap. 7 by Kevin K. Ohlemiller.

Finally, the roles of internal state and context in vocal communication are discussed in both laboratory and wild rodents by Laura M. Hurley and Matina C. Kalcounis-Rueppell in Chap. 8.

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Chapter 1
An Introduction to Rodent Bioacoustics

Micheal L. Dent

Abstract Rodents are a relatively diverse order of mammals that are found in abundance virtually all over the globe. The behavior of wild rodents is less well understood than that of laboratory rodents. Aboveground juvenile and adult rodents produce vocalizations that are used for communicating information about predators, mating readiness, hunger, and food availability. Subterranean rodents not only produce vocalizations but also drum their feet and bang their heads against burrows to communicate. The auditory system of rodents allows for detecting signals in quiet, discriminating between characteristics of communication signals, categorizing signals, and localizing sounds in space. Genetically manipulating laboratory rodents has elucidated much of what is known about auditory perception in mammals. Finally, the context and state of the rodent can have an influence on both the signal produced and the signal received. A common theme of the chapters in this volume is that a lot is known about bioacoustics in just a few species of rodents, while absolutely nothing is known about communication by most rodent species, presenting an opportunity for laboratory and field bioacousticians alike.

Keywords Acoustic communication · Animal communication · Chinchilla · Context · Discrimination · Hamster · Hearing · Mongolian gerbil · Mouse · Rat · Rodent anatomy · Sound localization · Subterranean communication · Ultrasonic vocalizations

1.1 Introduction

The fact that the Springer Handbook of Auditory Research (SHAR) has 65+ volumes without a rodent bioacoustics book is probably surprising to many followers of the series. However, even though rodents have not earned their own book until now, most, if not all, researchers in auditory laboratories are familiar with at least

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M. L. Dent et al. (eds.), *Rodent Bioacoustics*, Springer Handbook of Auditory Research 67, https://doi.org/10.1007/978-3-319-92495-3_1

two species of rodents used as models of hearing or communication. Indeed, studies of rodent bioacoustics are cited in the majority of the books in the SHAR series.

A vast majority of the hearing and vocal communication studies in nonhumans has been conducted on rodents. As a consequence, this book ties together several forms of acoustical research on rodents, bringing together neuroethologists, animal behaviorists, biologists, and clinicians to improve understanding of this mammalian group that has become so important to the scientific community. It is the intent of the authors of this volume that investigators will learn more about acoustic communication in their rodent species and thus will be able to utilize them in better (and perhaps additional) ways.

Studies of bioacoustics in rodents have taken two separate trajectories over the years. In the first trajectory, researchers have studied the behavior of numerous species of wild rodents in their natural habitats. These studies are somewhat scarce compared to the second trajectory in which researchers have used a few species of laboratory rodents as models for human hearing and speech. This has led to a very narrow group of rodent species that have been utilized to study hearing and acoustic communication signals. Many of these laboratory rodents are inbred so as to maintain genetic similarity and decrease between-subject variability. An understanding of the diversity of communication systems in rodents is lost as a result, which is fine for scientists interested in factors such as the genes encoding hearing loss, but the loss of diversity is problematic for comparative researchers interested in factors such as the influence of an animal's environment on auditory processing.

Chapters in this volume describe rodent bioacoustics from several different approaches, spanning the two trajectories mentioned above. Acoustic signals in air have been measured in both laboratory and wild rodents in both the field and in the laboratory, making Chap. 2 by Okanoya and Screven one of the most diverse chapters in terms of the number of rodent species studied. Subterranean communication is studied both in the laboratory and in the wild, although the laboratory studies usually involve rodents that were caught in the wild. Since underground recordings are so difficult, fieldwork is often avoided for these underground rodents. Chapter 3 by Schleich and Francescoli on subterranean signaling, like the chapter on rodent signals in air, thus takes a more neuroethological perspective than some of the other chapters in this volume.

The hearing chapter (Dent, Screven, and Kobrina, Chap. 4) reports laboratory behavioral and physiological auditory acuity of all rodents tested to date. While simple measures of hearing have been conducted on laboratory rodents and many species of nonlaboratory rodents, detailed analyses of hearing have not been measured in nonlaboratory rodents. Sound localization and binaural hearing (Lauer, Engel, and Schrode, Chap. 5) in rodents has suffered a similar fate: simple studies of directional hearing have been conducted on numerous rodent species, but the underlying anatomy and physiology and the more complicated measures of spatial hearing have been limited to a few laboratory rodent models.

The chapters on the anatomy of vocal communication and hearing (Kubke and Wild, Chap. 6) and on rodent models for genetic and age-related hearing loss (Ohlemiller, Chap. 7) also rely largely on data from laboratory rodents. Finally, the roles of state and context in vocal communication are discussed in both laboratory and wild rodents by Hurley and Kalcounis-Rueppel (Chap. 8), with particular importance placed on the effects of the natural environment on acoustic communication in the rodent species included in this chapter.

1.1.1 The Evolution and Lifestyles of Rodents

Rodents are a diverse order and, as mentioned in Sect. 1.1, little is known about acoustic communication in most species. The evolutionary history is fairly well mapped out, however. The order Rodentia contains over 2000 species, which is more than 40% of all mammalian species. The 2000 rodent species are spread across five suborders (Fig. 1.1) and thirty-six families. The suborders are: (1) Sciuromorphs (squirrel-shaped), which include dormice, groundhogs, chipmunks, and squirrels; (2) Castorimorphs, which include beavers, pocket gophers, kangaroo rats, and kangaroo mice; (3) Anomaluromorphs, which include springhares; (4) Myomorphs (mouse-shaped), which include hamsters, rats, and mice; and (5) Hystricomorphs (porcupine-shaped), which include porcupines, mole rats, chinchillas, and degus (Feldhamer et al. 2015). This classification is by no means universally agreed upon (reviewed in Honeycutt et al. 2007).

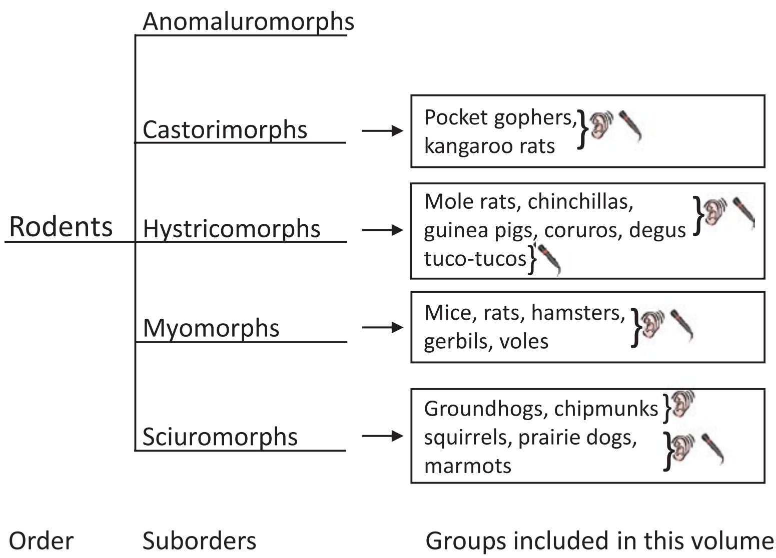

Fig. 1.1 The five suborders of the rodentia order and groups of rodents included in this volume. No groups of anomaluromorphs have been studied in the field of bioacoustics. Multiple species from the other orders have been included in the chapters of this volume. Auditory acuity measurements in a group are denoted with the ear icon and vocalization measurements in a group are denoted with the microphone icon

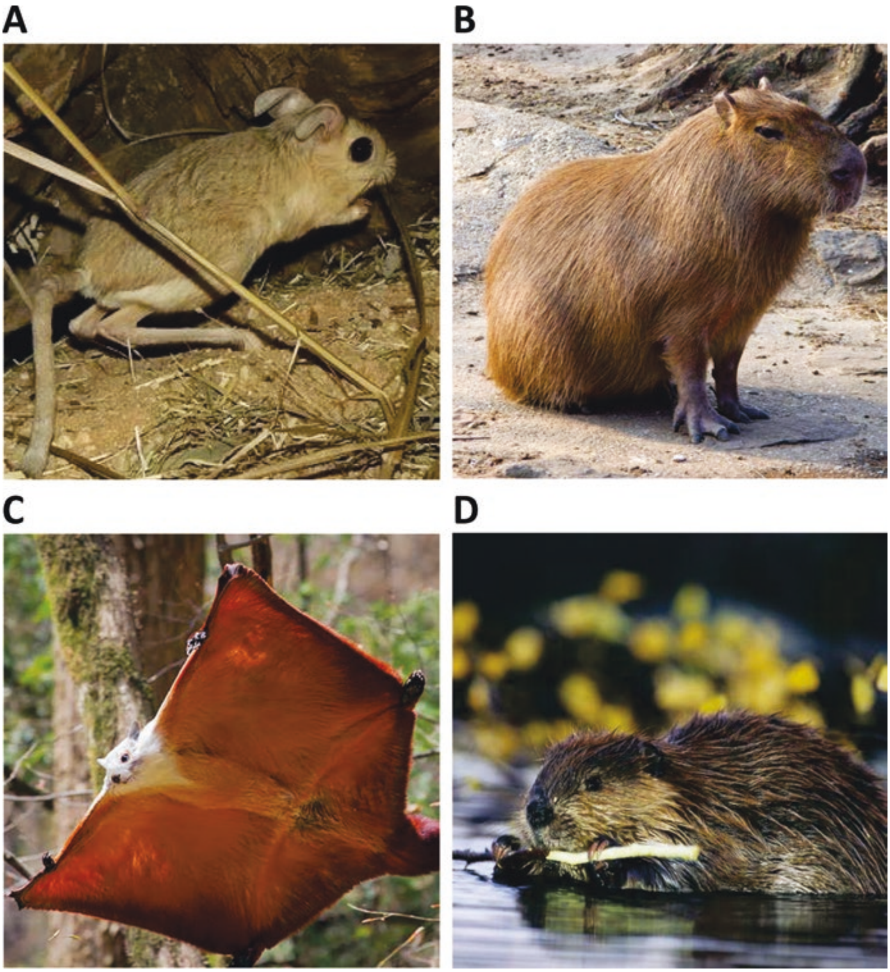

Fig. 1.2 Diversity of rodents. (**a**) The smallest mammal, the pygmy jerboa (*Allactaga tetradactyla*), and (**b**) the largest mammal, the capybara (*Hydrochoerus hydrochaeris*); (**c**) giant flying squirrel (*Petaurista sp.*); (**d**) beaver (*Castor sp.*). (**a** Digital image from upload.wikimedia.org/wikipedia/commons/3/3c/Allactaga_elater_Plzen_zoo_02.2011.jpg; **b** Digital image from www.flickr.com/photos/lorentey/5592629831; **c** Digital image from img.burrard-lucas.com/china/full/giant_flying_squirrel.jpg; **d** Digital image from https://c2.staticflickr.com/8/7153/6667988291_efec293851_b.jpg)

Rodents as a group exhibit vast amounts of diversity and adaptability. The smallest rodents, for example, the pygmy jerboa (*Allactaga sp.*; Myomorph suborder) (Fig. 1.2a), are under 5 g, while the largest rodents, for example, the capybara (*Hydrochoerus hydrochaeris*; Hystricomorph suborder), are over 50 kg (Fig. 1.2b) (e.g., Feldhamer et al. 2015). Rodents are found wild on all continents except Antarctica, and thus they have adapted to living in wet and dry, hot and cold, aboveground and subterranean, and light and dark environments, primarily solitary or in large social groups (Feldhamer et al. 2015). Rodents with special adaptations include giant flying squirrels (*Petaurista sp*.; Sciuromorph suborder), who have evolved folds of skin that allow them to glide from tree to tree to avoid predation (Fig. 1.2c), and beavers (*Castor sp*.; Castorimorph suborder), who have structural specializations allowing them to keep their mouths open while underwater so that they can carry branches and gnaw (Fig. 1.2d) (e.g., Vaughan 1985).

Convergent evolution of lifestyles is also common across rodents. For instance, subterranean rodents are found in Africa, Asia, and North and South America. Various morphological and physiological specializations for surviving underground, including shorter limbs, flat skulls, and tolerance of high carbon dioxide environments, have evolved numerous times (reviewed in Honeycutt et al. 2007). Overall, rodents are remarkably adaptive creatures who, as a group, have undergone fewer extinctions relative to other mammals (Honeycutt et al. 2007).

The defining rodent characteristic is having a single pair of upper and lower continuously growing incisors. Rodents have thus been referred to as "gnawing machines" (Druzinsky 2015). The incisors are used not only to eat but also to excavate tunnels and for defense. Most rodents are either herbivores or opportunistic omnivores. Some rodents, like the grasshopper mouse (genus *Onychomys*), are predatory carnivores, preying on insects and other mice. Rodents of all sizes are also food sources for a variety of predators and use the incisors to keep those predators away.

Rodents range from being relatively social animals (e.g., prairie voles, *Microtus ochrogaster*) to living solitary lifestyles (e.g., woodchucks, *Marmota monax*) (Lacey and Sherman 2007). Mating systems of rodents also vary widely, from monogamous California mice (*Peromyscus californicus*) to promiscuous Gunnison's prairie dogs (*Cynomys gunnisoni*) (Waterman 2007).

Social rodents communicate information about territories, sexual receptivity, predators, and food through multiple sensory channels, including chemosensory, visual, and auditory modalities. The sense of olfaction in most rodents is known to be excellent (e.g., Hurst et al. 2001). Olfaction is important for social, sexual, and antipredator behaviors in rodents (Arakawa et al. 2008). Visual acuity, on the other hand, varies widely among rodent species (Francescoli 2000). Auditory abilities fall somewhere in between vision and olfaction in terms of the range of acuities across species (Dent, Screven, and Kobrina, Chap. 4).

1.1.2 Rodent Auditory Behavior

The highly successful (at least from an evolutionary perspective) and diverse mammalian order of rodents is probably not thought of as an especially vocal group of animals for several reasons. First, as mentioned in Sect. 1.1.1, rodent communication is heavily olfactory. Chemical signals have advantages over acoustic signals in that they remain in the air even after signalers have left, allowing them to depart from a potentially dangerous situation but still enabling them to warn others (Bradbury and Vehrencamp 2011). Since rodents serve as a food source for many birds, larger mammals, and reptiles, effective anti-predatory communication is vital for survival, and olfactory signaling is just a part of a rodent's communicative repertoire. Rodents also use scent signals for marking territories (e.g., blind mole-rats, *Spalax ehrenbergi*) and for sexual selection (e.g., prairie voles, *Microtus ochrogaster*) (Roberts 2007).

A second reason rodents may have been overlooked as a vocal group is because many of their acoustic signals are ultrasonic (above 20 kHz) (Portfors 2007), infrasonic (below 20 Hz), or seismic (vibrating the ground) (Narins et al. 2016). Thus, without special recording equipment, many of the signals used by rodents for communication are not detectable by humans. Signals that are undetectable to humans tend to receive less attention relative to studies of signals that fall into the human auditory range. Nonetheless, it is known that acoustic communication in rodents is widespread. Rodents produce vocalizations during play, for mate attraction, as alarms during a dangerous situation, and as pups to urge their mother's return, to name just a few examples (e.g., Portfors 2007). Acoustic signals, like their olfactory counterparts, do not require daylight for communication to occur, allow the animals producing them to be somewhat cryptic when signaling, for example, narrowband signals which are often difficult to localize (e.g., Bradbury and Vehrencamp 2011). Acoustic signals also allow for great flexibility in communication because the animals can change the frequency range, duration, or other temporal characteristics to adjust the meaning of calls (e.g., Bradbury and Vehrencamp 2011). The auditory system of rodents allows them to be able to discriminate these changes for effective communication (Dent, Screven, and Kobrina, Chap. 4).

1.1.3 Laboratory Rodent Bioacoustics

The human–rodent connection is strong, and most of the habitats inhabited by humans are also inhabited by rodents (Feldhamer et al. 2015). Rodents such as mice have been benefiting from humans for thousands of years. Previously, farming was believed to have led to the influx of mice in human settlement locations. Fossil records suggest that mouse domestication began closer to 15,000 years ago, much earlier than the advent of agriculture, and was correlated with decreases in human mobility (Weissbrod et al. 2017). As human populations grew and became sedentary, so, too, did house mouse populations. House mice and other rodents (e.g., rats) have long been thought of negatively as pests who eat farmers' crops and as vectors for a number of infectious diseases (Feldhamer et al. 2015). However, some species can also have positive impacts on humans, for example, muskrats (*Ondatra zibethicus*) and beavers (*Castor canadensis*) that have been used for fur (Feldhamer et al. 2015), giant African pouched rats (*Cricetomys gambianus*) that are trained to detect landmines and tuberoculosis (Poling et al. 2010, 2011), and the various rodent species used in laboratories around the world for valuable medical research of all types. Thus, the human–rodent relationship has both positive and negative aspects.

Rodents, especially the Norway rat (*Rattus norvegus*), became popular for laboratory studies of social, feeding, reproductive, and emotional behaviors, of their sensory capabilities, and for studies of conditioning and learning in the early 1900s (Beach 1950). A number of characteristics makes rats (and mice) especially attractive for laboratory research, including their short lifespans, small size, large litter sizes, and ease of handling (Feldhamer et al. 2015). They are also relatively easy to train. Most scientists would say that rats and mice have become indispensable to research programs around the world. Thus, much of what is known about hearing and vocalizations in rodents comes from just those two species that have been tested in the laboratory.

The sequencing of the mouse genome in 2002 (Waterston et al. 2002), followed by the rat genome in 2004 (Gibbs et al. 2004), only increased the utility of these animals as research subjects since genetically engineered strains mimicking human diseases and disorders could be developed more easily. In the laboratory, rats and mice are used as models for human communication and hearing disorders and are involved in studies on hearing loss and prevention, hormones, and auditory plasticity, to name just a few topics. The importance of acoustic communication to rodents and the significance of these animals to biomedical research are summarized in the chapters in this book. When possible, field studies on acoustic communication in wild rodents are also included.

1.2 Rodent Vocalizations

Okanoya and Screven (Chap. 2) describe the diversity of vocalizations produced by rodents, both in terms of the contexts and environments in which the vocalizations are produced and in their acoustic characteristics. Physical factors in the environment, such as vegetation and high frequency attenuation, affect sound propagation and probably influence the vocalizations produced under different contexts. Specific events, such as isolation distress in pups, social and sexual coordination, nearby predators, anticipation of an aversive occurrence, aggressive encounters, play, and finding food, all give rise to vocalizations. This chapter summarizes the rodents' complex acoustic communication system for coordinating many types of behaviors and social situations.

1.3 Subterranean Communication

Schleich and Francescoli (Chap. 3) describe three decades of studies on acoustic communication in subterranean rodents. More than 250 of the 2000+ species of rodents spend most of their lives underground. These rodents range from strictly subterranean, which live completely underground, to fossorial, which live underground but also engage in other activities at the surface. The underground burrows inhabited by rodents are physically very different from the outside, leading to morphological specializations in subterranean rodents and leading to stark differences in communication in these species relative to aboveground rodents. This chapter discusses the vocalizations and seismic signals of subterranean rodents, correlating them to context, social group structure, and habitat.

1.4 Hearing

Dent, Screven, and Kobrina (Chap. 4) describe hearing in rodents. The ability to detect, discriminate, localize, and identify acoustic signals is important for all animals, and rodents are no exception. Rodents can be trained using operant conditioning to report detecting a sound, a change in a repeating background of sounds, or indicate to which category a sound belongs. The training process for some rodents (e.g., mice) is more time consuming than the training process for other rodents (e.g., rats). Thus, some researchers have also measured auditory acuity using much speedier reflex behavioral or physiological methods, although these methods have their limitations. Audiograms, frequency selectivity, frequency discrimination, intensity discrimination, temporal resolution, and the perception of complex sounds have all been measured in various species of rodents and are summarized in this chapter.

1.5 Sound Localization and Spatial Hearing

Lauer, Engel, and Schrode (Chap. 5) describe both the abilities of rodents to locate sounds in space and the underlying neural circuitry involved in the process. While small rodents must rely on interaural level differences at high frequencies to localize sounds, larger rodents may utilize interaural time differences. This chapter summarizes the sound localization acuity and underlying neural circuitry that support localization in rodents and compares it to other mammals.

1.6 Anatomy of Vocal Communication and Hearing

Kubke and Wild (Chap. 6) describe how rodents produce and detect acoustic signals. Even though some rodents are known to produce ultrasonic vocalizations, an unusual characteristic among mammals other than bats and some marine mammals, the muscles and nerves involved in the production of vocalizations are similar across rodents and other mammals. Some small rodents have unusual middle ears that are probably specializations for high frequency hearing, but most rodents have generally unspecialized auditory pathways. The auditory midbrain and cortex of rodents are responsive to natural vocalizations. This chapter summarizes what is known about other factors influencing the coding of vocalizations, including social experience.

1.7 Rodent Models for Genetic and Age-Related Hearing Loss

Ohlemiller (Chap. 7) describes genetic and age-related pathologies of hearing. As in the other chapters, the effects of genes and age on hearing have only been studied in a few species of rodents. There is quite a bit of overlap in the genes known to cause deafness in humans and rodents, making rodents useful models of hearing loss in most cases. Both inbred and outbred rodents are used in studies of hearing and hearing loss. While no models are perfect, different models are good at mimicking different diseases or pathologies. This chapter summarizes how these models have been invaluable for teasing apart the genetic, aging, sex, and anatomical contributions to hearing loss.

1.8 State and Context in Vocal Communication

Hurley and Kalcounis-Rueppell (Chap. 8) describe the influences of state and context in vocal communication of rodents. To fully understand acoustic communication in rodents, the characteristics of the sender and receiver must be studied, but the communication "scene" needs to be understood as well. The scene, or context, for each member involved in the communication process can include the environment where the animals live, the reproductive phase of the parties engaging in communication, and the developmental life history of the subjects. Understanding the context reduces the ambiguity that may be present in a vocalization, allowing the animal to take the appropriate action. The scene can be broken further into internal and external factors. Internal factors include self-identity and internal state (e.g., motivation levels). External factors include environmental conditions, such as the weather and the identity of a partner. This chapter summarizes the factors involved in communication in rodents and describes their impacts on both the sender and the receiver.

1.9 Summary

The chapters in this book highlight what is known about rodent bioacoustics. Given the great diversity in communication signals and auditory processing of some other vertebrates (e.g., birds), one might also expect to see such diversity in rodent acoustic communication. Unfortunately, not much is known about the production and reception of acoustic signals by most rodent species. The following questions remain unanswered for most rodents: Have temperature, humidity, and vegetation driven evolutionary changes in the properties of acoustic signals? Has anthropogenic noise altered vocalizations of rodents in similar ways as it has in other animals? Are all rodents specialized to discriminate between their own vocalizations?

Does the size of the rodent play a role in binaural acuity? Characterizing the natural behavior of wild rodents is important for the conservation of these mammals. It is hoped that this book will inspire scientists to heed the advice of Frank Beach (1950): "It would be much better if some of our well-trained experimentalists were encouraged to do a little pioneering."

Compliance with Ethics Requirements: Micheal Dent declares that she has no conflict of interest.

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