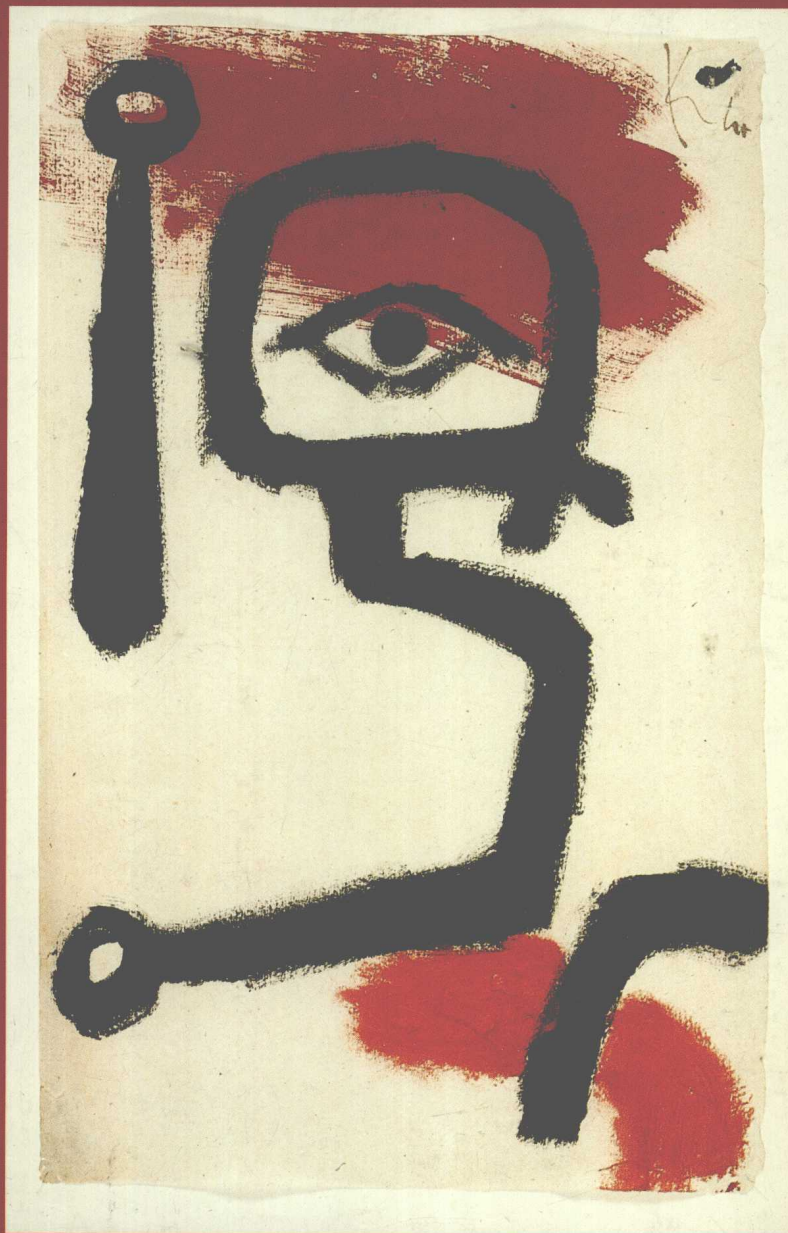


S E C O N D E D I T I O N

PERCEPTION



ROBERT SEKULER/RANDOLPH BLAKE

SECOND EDITION

PERCEPTION

Robert Sekuler

Brandeis University

Randolph Blake

Vanderbilt University

McGRAW-HILL PUBLISHING COMPANY

New York St. Louis San Francisco Auckland Bogotá Caracas Hamburg
Lisbon London Madrid Mexico Milan Montreal New Delhi Oklahoma City
Paris San Juan São Paulo Singapore Sydney Tokyo Toronto

PERCEPTION

Copyright © 1990 by McGraw-Hill, Inc. All rights reserved.

Copyright © 1985 by Alfred A. Knopf, Inc. All rights reserved.

Printed in the United States of America. Except as permitted under the United States Copyright Act of 1976, no part of this publication may be reproduced or distributed in any form or by any means, or stored in a data base or retrieval system, without the prior written permission of the publisher.

2 3 4 5 6 7 8 9 0 DOH DOH 9 5 4 3 2 1 0

ISBN 0-07-056065-X

This book was set in Times Roman by Waldman Graphics, Inc.

The editors were Barry Ross Fetterolf and Tom Holton.

R. R. Donnelley & Sons Company was printer and binder.

Cover painting: *Paukenspieler*, 1940.270, by Paul Klee. Kunst Museum, Bern.

Library of Congress Cataloging-in-Publication Data

Sekuler, Robert.

Perception / Robert Sekuler, Randolph Blake. — 2nd ed.

p. cm.

Includes bibliographical references.

ISBN 0-07-056065-X

1. Perception. I. Blake, Randolph. II. Title.

BF311.B54S46 1990

153.7—dc20

89-48905

CIP

PREFACE

Human beings have always wondered about how they perceived the world in which they lived. In modern times, this wonder has inspired behavioral and biological scientists to take up a systematic study of perception. Building on the cumulative efforts of all these people, this book explains seeing, hearing, touching, smelling, and tasting to students of perception.

Organization and Coverage The introductory chapter summarizes the motivations that inspire people to study perception, as well as the various approaches that such study can take. It also outlines the framework on which the entire text is constructed. Chapters 2 through 7 discuss seeing—the biological basis of vision and the perception of pattern, color, and depth. The treatment of seeing concludes in Chapter 8 with an essay on the perception of visual events. The most detailed chapters in the book are Chapters 9 and 10, on hearing, Chapter 11, on touch, and Chapter 12, on smelling and tasting. Chapter 13 concludes the text with a consideration of the important interactions between knowledge and perception.

Special Features Our book has several noteworthy features. Central topics are presented in historical context, underscoring that the contemporary study of perception is part of an unfolding intellectual process. At the same time, our source materials are strongly biased toward items only recently published. Because we want students to appreciate developments at the frontiers of perception, we give thorough coverage of “hot,” rapidly developing topics. For ex-

ample, one chapter provides a comprehensive treatment of visual spatial frequency analysis, another highlights a sensory system’s amazing plasticity. This special stress on the most recent work demonstrates that perception is a living and growing field.

The extensive program of more than 250 illustrations, many new to this edition, is another of this book’s most important features. Our combined forty years of teaching have taught us that students don’t always see in a graph or diagram exactly what was intended. So instead of merely directing student readers to “look at the figure,” we have crafted the text, figures, and figure captions to ensure accurate interpretation of the illustrative material. In addition, we have given extra care to the graphic presentation of complex ideas. Such ideas are often conveyed in this book by a short series of illustrations, with each illustration in a series introducing additional concepts. This approach enables every reader to get the point—even those who are novices at interpreting graphs and diagrams. Finally, illustrations that depict previously published experimental results have been adapted and redrawn to maximize clarity and consistency of presentation.

We have attempted to make our treatment of perception an integrated one, in part by linking ideas across chapters. These linkages reflect the fact that different areas in perception often utilize similar techniques and related theoretical ideas. Our text is integrated in another way, blending anatomy, physiology, and psychophysics. The information and ideas from each of these three approaches have been carefully

selected to ensure a coherent, complete presentation. Structure and function become more comprehensible and memorable when they are integrated.

Vocabulary and Methods of Perceptual Research (Glossary and Appendix) Because the study of perception draws upon many different disciplines—physics, chemistry, anatomy, psychology, and medicine, among others—its technical vocabulary incorporates the terminology of those disciplines. Beginning students of perception are often bewildered by the flood of new terms that they must master. Recognizing this problem, we have introduced only those terms that are absolutely necessary to the discussion. Each term is carefully defined when it is first used, and all these terms appear in a Glossary at the back of the book.

We have also kept detailed, abstract descriptions of research methods to a minimum. Where appropriate, we explain particular methods in enough detail that the student reader can appreciate the methods and whatever constraints they impose on results and conclusions. Various methods for studying perception are discussed within the context of the specific problems that they were designed to solve. By integrating methods and results, we hope to facilitate the reader's genuine appreciation of both. An Appendix provides much additional information about conventional behavioral methods for studying perception. The Appendix also describes contemporary variants of those methods: forced-choice procedures, sensory decision theory, and adaptive psychophysical methods. The Appendix presents these methods within a historical framework, enabling the student to understand not only the methods but also the reasons for their development.

Relations to Everyday Life Since perception is not just an abstract, scientific discipline, but an integral part of everyday life, this book consistently relates scientific research on perception to the reader's own perceptual experiences. To underscore the relationship between science

and everyday experience, we present many simple, interesting demonstrations that readers can perform on their own with little or no equipment. Also, in order to anchor the discussion in the reader's own experience, the text emphasizes the everyday behavioral needs that seeing, hearing, smelling, tasting, and touching are designed to satisfy—the functions of perception. This functional approach to perception is highlighted in the special-topic boxes that appear throughout the text. Many of these boxes discuss clinical disorders and their fascinating perceptual consequences. Some students will be interested in learning about these disorders for personal reasons; all students should find that the study of perceptual disorders provides insight into the nature of normal perception.

Key Changes for this Edition Instructors who have used the first edition of this book will be pleased that the new edition adheres to the same general thematic approach and organization. There are, however, a number of notable changes that provide a fresher, more lively portrayal of the field of perception. You will find, for example, that Chapter 2 presents influential new work on how vision is affected by the nature of the retinal mosaic. Chapter 3 now discusses retinal ganglion cells in terms of the P and M classification that has supplanted the earlier X and Y distinction. This newer classification better describes the ganglion cell population in the primate retina and it dovetails nicely with what is known about cell categories in the lateral geniculate nucleus and in visual cortex. Chapters 4 and 6 now take note of these parallels. Chapter 4 also includes a discussion of multiple visual representations, or maps, within the brain. The discussion of spatial frequency analysis, in Chapter 5, now casts that material within the context of form perception at multiple spatial scales. The material on motion perception in Chapter 8 in this new edition includes coverage of exciting work on cortical area MT, a higher brain region that appears specialized for the analysis of global motion information. Chapter 9 now takes notice of new

developments in our understanding of hair cell function. Into the chapter on taste and smell we've integrated new ideas about smell's incredible sensitivity and additional material on the basis of food preferences. Also, we've added an entirely new chapter on touch perception, a topic that received virtually no coverage in the earlier edition. As you will see, impressive new discoveries about touch add to the excitement of teaching a course on perception. Chapter 13, which focuses on knowledge and perception, has been reworked to incorporate both old and the new: the chapter presents Williams James' century-old but still powerful insights, as well as the latest findings on the physiology of visual attention. The Appendix, on behavioral methods, now notes the utility of theoretical, "ideal" observers that can provide benchmarks for real, human performance. Finally, we should note that some of the philosophical material in Chapter 1 has been revised in order to give a stronger and clearer treatment of these important foundational issues.

These are just some of the additions and revisions in this second edition. Earlier users will also notice the book's handsome new layout and its many new or revised illustrations and photographs. Scrutiny of the reference list would disclose that about 250 of the references are new to this edition, with most of the new references representing contributions published in the last three years.

In preparing the first and second editions of the book, we benefited greatly from the comments and criticisms of many people. Special credit should be given to those individuals who reviewed various chapters and sections. These include:

Martin Banks, University of California at Berkeley

William P. Banks, Pomona College

Linda M. Bartoshuk, Pierce Foundation, Yale University

Patrick J. Bennett, University of Toronto

Ira H. Bernstein, University of Texas at Arlington

Irving Biederman, University of Minnesota

Richard Bowen, Loyola University of Chicago

Edward Carterette, University of California at Los Angeles

Peter Dallos, Northwestern University

David S. Emmerich, State University of New York, Stony Brook

Trygg Engen, Brown University

Robert Gesteland, University of Cincinnati

Lewis O. Harvey, University of Colorado

Morton Heller, Winston-Salem State University

James Hillenbrand, Northwestern University

Leo Hurvich, University of Pennsylvania

Frederick Kitterle, University of Toledo

Eileen Kowler, Rutgers University

Jon Kaas, Vanderbilt University

Herschel W. Leibowitz, Pennsylvania State University

Robert M. Levy, Indiana State University

Jack Loomis, University of California at Santa Barbara

Michael Merzenich, University of California at San Francisco

Matthew Olson, Hamline University

Mark Perkins, AT&T Laboratories

Nancy Perrin, Portland State University

Steve Poltrok, University of Denver

James R. Pomerantz, Rice University

Tim Pons, National Institutes of Health

Keith Rayner, University of Massachusetts at Amherst

William Newsome, Stanford University

Robert Pachella, University of Michigan
Phillip Russell, Northwestern University
Allison Sekuler, University of California at Berkeley
Joseph Verillo, Syracuse University
Benjamin Wallace, Cleveland State University
Brian Wandell, Stanford University
William H. Warren, Jr., Brown University
Gerald S. Wasserman, Purdue University
Scott N.J. Watamaniuk, Smith-Kettlewell Institute
John S. Werner, University of Colorado
David H. Westendorf, University of Arkansas
David R. Williams, University of Rochester
William A. Yost, Loyola University of Chicago
James L. Zacks, Michigan State University

We also thank Gregory C. Phillips who gave cheerfully of his time and talents to prepare some of the computer graphics for the book. Kathy Mandell rendered invaluable help by tracking down obscure reference materials and ensuring that they stayed put long enough for us to use them. We are particularly grateful to Carolyn Shufeldt, whose frank comments on early drafts of each chapter were very helpful to us in revising those drafts. Thanks are owed to our students, colleagues, and especially our families of their tolerance during our preoccupation with this project. Finally, we thank the excellent editorial and production staff at McGraw-Hill, in particular Susan Badger, senior editor; Renee Shively Leonard, assistant editor; Tom Holton, editing supervisor.

ROBERT SEKULER
RANDOLPH BLAKE

PERCEPTION

ABOUT THE AUTHORS

ROBERT SEKULER is the Louis and Frances Salvage Professor of Psychology at Brandeis University, Waltham, Massachusetts, where he also serves as Provost and Dean of Faculty. Sekuler earned his Ph.D. at Brown University in 1964 and then held a postdoctoral fellowship at M.I.T. Subsequently, he was on the faculty at Northwestern University, where he was John Evans Professor of Neuroscience, and had the rank of professor in the departments of psychology, ophthalmology, and neurobiology. An expert in the perception of motion and on perceptual changes in aging, Sekuler has published more than 120 scientific papers. He is past Chair of the Committee on Vision of the National Academy of Sciences and serves on the board of the Hugh Knowles Center on Hearing and Its Preservation. Sekuler is a fellow of the Optical Society of America and the American Academy of Optometry; he is a member of the Human Factors Society, the American Psychological Society, the American Begonia Society, and the Association for Research in Vision and Ophthalmology.

RANDOLPH BLAKE is currently professor and chairman of the Department of Psychology at Vanderbilt University, Nashville, Tennessee. Prior to this appointment he was on the faculty of Northwestern University for fourteen years. He received his Ph.D. from Vanderbilt in 1972 and then spent two years as a postdoctoral fellow in the Sensory Sciences Center at the University of Texas Graduate School of Biomedical Sciences. Blake has published extensively in major psychology and neuroscience journals and has contributed chapters to edited books including *Models of the Visual Cortex*, *Frontiers of Visual Science*, and *Development of Perception*. His research, supported by grants from the National Science Foundation and the National Institutes of Health, focuses on visual perception with particular emphasis on binocular vision and the neural bases of pattern perception. In recognition of his research contributions, Blake received a Career Development Award from the National Institutes of Health and the American Psychological Association's Early Career Award for Distinguished Scientific Contribution. In 1987 Blake was elected as a Fellow of the American Association for the Advancement of Science. He is a past member of the Committee on Vision of the National Academy of Sciences/National Research Council and the Sensory Sciences Advisory Panel of the National Science Foundation; he is currently a member of the executive committee of the Council of Graduate Departments of Psychology. His hobbies include bicycling, music, and collecting textiles.

CONTENTS

PREFACE

xiii

1

INTRODUCTION TO PERCEPTION

1

Aspects of Perception	2
BOX 1.1 Seeing the Invisible	4
Why Study Perception?	7
Ways of Studying Perception	11
BOX 1.2 Hearing Lightning and Seeing Thunder	12
The Psychological and Biological Approaches to Perception	13
BOX 1.3 Should You Answer the Phone?	16
Why Emphasize Vision?	21
Summary and Preview	22
Key Terms	22

2

THE HUMAN EYE

23

Designing the Organ of Vision	23
BOX 2.1 Eyes That Never Stand Still	27
The Structure of the Human Eye	30
BOX 2.2 In the Blink of an Eye	31
The Eye as Optical Instrument	39
BOX 2.3 Supplying Blood to the Retina	40
BOX 2.4 Some Origins of Myopia	47
BOX 2.5 Seeing Under Water	50
The Photoreceptors	52
BOX 2.6 A Gap in Your Visual Field	55
Summary and Preview	60
Key Terms	60

3

THE EYE AND SEEING 61

The Retinal Ganglion Cells	62
BOX 3.1 Blacker Than Black	66
Perceptual Consequences of Center/Surround Antagonism	70
Sensitivity Versus Resolution	79
BOX 3.2 When Lightness Constancy Fails	80
BOX 3.3 Adding Photons over Time and Space	82
BOX 3.4 Visual Acuity: The Meaning of 20/20 Vision	87
BOX 3.5 Does the Electric Company Give You Your Money's Worth?	91
BOX 3.6 Recovering from Light	95
Summary and Preview	96
Key Terms	96

4

CENTRAL VISUAL PATHWAYS 97

The Optic Nerve	97
The Superior Colliculus	100
The Lateral Geniculate Nucleus	101
The Visual Cortex	105
BOX 4.1 Look Both Ways Before Crossing	106
BOX 4.2 Some Illuminating Findings on Blindness	110
BOX 4.3 The Oblique Effect	114
Can Receptive Fields Explain Visual Perception?	122
BOX 4.4 Cortical Color Blindness	123
BOX 4.5 The Tilt Aftereffect	126
Summary and Preview	131
Key Terms	131

5

SPATIAL VISION AND PATTERN PERCEPTION 132

What Defines an Object?	132
What Defines "Form"?	133
Traditional Approaches to Form Perception	134
A Contemporary Approach to Form Perception	138
BOX 5.1 Practical Uses of the CSF	151
BOX 5.2 When Things Go Wrong with Pattern Vision	159
BOX 5.3 Not Seeing the Forest for the Trees	163
BOX 5.4 The Size Aftereffect	165
BOX 5.5 It Pays to Pay Attention	170
Summary and Preview	171
Key Terms	171

6

COLOR PERCEPTION**172**

Why Is It Important to See Colors?	172
What Are the Units of Color Perception?	173
BOX 6.1 Newton Stirs Up a Hornet's Nest	178
BOX 6.2 Mixing Colors	182
The Trichromacy of Human Vision	184
Color's Opponent Character	192
BOX 6.3 Color Contrast	193
BOX 6.4 A World Seen Through Green Glasses	197
Abnormalities of Color Perception	201
BOX 6.5 Answers to Some Common Questions About Color	204
Summary and Preview	206
Key Terms	206

7

DEPTH PERCEPTION**208**

Oculomotor Cues	209
Binocular Visual Information: Stereopsis	211
BOX 7.1 Cooperation Between the Two Eyes	212
BOX 7.2 Competition Between the Two Eyes	219
BOX 7.3 Coordination Between the Two Eyes	221
Monocular Visual Depth Information	222
Depth, Illusions, and Size Constancy	235
Summary and Preview	239
Key Terms	240

8

**ACTION AND THE PERCEPTION
OF EVENTS****241**

What Is an Event?	242
Biological Motion	242
BOX 8.1 Flicker	243
The Visual Guidance of Locomotion	248
BOX 8.2 Not Watching Where You're Going	253
Eye Movements: Their Aims and Effects	254
BOX 8.3 No Movements, No Seeing	255
BOX 8.4 Learning to Move Your Eyes	259
Two Visual Systems	262
BOX 8.5 Perceptual Errors Can Cause or Prevent Accidents	263
The Neural Basis of Motion Perception	265

Apparent Motion	269
BOX 8.6 Looking One's Age	274
Summary and Preview	276
Key Terms	276

9

THE EAR AND AUDITORY SYSTEM 277

Aspects of Sound	277
BOX 9.1 Clocking the Speed of Sound	279
BOX 9.2 Cries and Whispers	284
The Auditory System: The Ear	286
BOX 9.3 Resonant Frequencies: Is It Live or Is It . . . ?	287
BOX 9.4 The Role of the Inner and Outer Hair Cells in Hearing	295
BOX 9.5 A Peculiar Sort of Microphone	298
The Auditory System: The Auditory Pathways	304
Summary and Preview	311
Key Terms	311

10

HEARING 312

The Range and Limits of Hearing	312
BOX 10.1 Hearing Loss	315
Loudness Perception	321
BOX 10.2 Magnitude Estimation and the Power Law	326
Pitch Perception	331
BOX 10.3 What Is a Melody?	335
Sound Recognition: Judging <i>What</i> the Source of a Sound Is	339
Sound Localization: Judging <i>Where</i> a Sound Originates	341
BOX 10.4 Nature Rewards Those Who Are Small	344
The Perception of Speech Sounds	350
Summary and Preview	358
Key Terms	358

11

TOUCH 359

Touch's Different Qualities	360
Sensitivity and Acuity of Touch	361
BOX 11.1 Illusions of Touch: Keep Your Fingers Crossed	364
BOX 11.2 Giving Touch a Rough Time	366
BOX 11.3 Seeing with the Hands	369
Physiology of Touch	369

Detection and Intensity Judgments	371
Speculations about Cortical Organization	378
Active Touch	379
BOX 11.4 The Right Touch Saves Lives: Breast Self-Examination	379
Plasticity in the Somatosensory Cortex	381
Key Terms	383

12

SMELL AND TASTE 384

The Sense of Smell	385
BOX 12.1 Gender-Related Odors	386
BOX 12.2 Introducing Multidimensional Scaling	391
BOX 12.3 Is Olfaction a Dual Sense?	395
BOX 12.4 Smell, Taste, and Literature	407
The Sense of Taste	409
BOX 12.5 Some Like It Bitter Better Than Others	416
BOX 12.6 The Taste of Water: An Aftereffect	419
The Interaction Between Taste and Smell	421
Summary and Preview	423
Key Terms	423

13

KNOWLEDGE AND PERCEPTION 424

A Framework: Top-Down Versus Bottom-Up	425
Uncertainty and Perception	425
BOX 13.1 “Doctor, Is It Broken?”	426
Ambiguity and Perception	429
BOX 13.2 Did I See It or Just Imagine It?	433
Familiarity and Perception	436
BOX 13.3 Reading Music	444
Perceptual Aspects of Reading	445
Perception Without Knowledge	449
Summary	450
Key Terms	450

APPENDIX

SOME BEHAVIORAL METHODS FOR STUDYING PERCEPTION 451

The Birth of Psychophysics	451
Fechner’s Three Methods	453
Modifications of Fechner’s Methods	456

Forced-Choice, Objective Methods	458
Sensory Decision Theory	460
Key Terms	462
 REFERENCES	 463
 GLOSSARY	 497
 NAME INDEX	 509
 SUBJECT INDEX	 514

CHAPTER

1

INTRODUCTION TO PERCEPTION

The world is filled with objects and events that combine to create a kaleidoscope of potential information. Though much of that information is irrelevant for people's daily needs, some of it is absolutely essential. So that they can use this information effectively, human beings are equipped with specialized machinery for capturing this information and for translating it into a language that can be understood by the nervous system. In this translated form, the selected information is digested by the brain, culminating in perceptions of the world. These perceptions then guide people's actions in the world around them.

As we've just described it, **perception** is the final link in a chain of related events. To understand perception completely, you must understand each link in the chain. To begin, you must know something about the environment in which you live, for this environment determines what there is to perceive. This first link in the chain is described using terms borrowed from physics, because stimulation comes in various forms of physical energy: thermal, mechanical, acoustic, and electromagnetic. The physical energy that initiates the chain of events is called a **stimulus** (plural "stimuli").

Next, you have to specify how the nervous system converts these physical energies into neural events. Known as **sensory transduction**, this conversion process requires an understanding of the specialized sensory receptors

such as those contained in the eye and the ear. Once this transduction has been achieved, objects and events are represented solely as patterns of neural impulses within the various sensory nerve fibers. From this point on, all further elaboration and editing of the sensory information must be performed using this neural representation.

A complete understanding of perception must include a thorough description of conscious experience, the final product in this chain of events. A great many techniques have been developed by psychologists for systematically cataloging the experiences of people and relating these experiences to patterns of physical stimulation. The enterprise of relating physical stimulation to perceptual events is known as **psychophysics**. By specifying the relation between physical and perceptual events, psychophysics provides important clues to unraveling the intervening events.

According to the view spelled out above, perception represents the final product in a chain of events stretching from events in the physical world external to the perceiver, through the translation of those events into patterns of activity within the perceiver's nervous system, culminating in the perceiver's experiential and behavioral reactions to those events. This sequence is illustrated in Figure 1.1. Let's now consider several important implications of this way of thinking about perception.

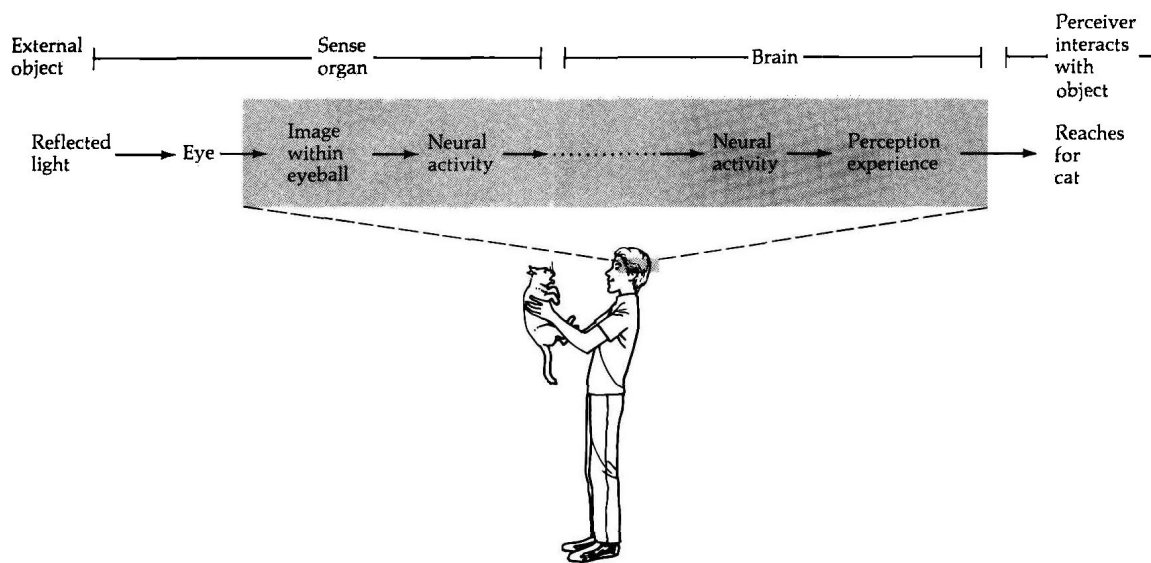


FIGURE 1.1

Sequence of major events leading to a percept.

ASPECTS OF PERCEPTION

PERCEPTION AS A BIOLOGICAL PROCESS

In this book, we approach perception as a *biological* process. In order to be perceived, *any* information about events in the world must be registered by the sensory nervous system. The noted neuroscientist Vernon Mountcastle has described this constraint very vividly:

Each of us lives within . . . the prison of his own brain. Projecting from it are millions of fragile sensory nerve fibers, in groups uniquely adapted to sample the energetic states of the world around us: heat, light, force, and chemical composition. That is all we ever know of it directly; all else is logical inference. (1975, p. 131)

Mountcastle is pointing out that sensory nerve fibers are the only link to the external world; they alone provide the communication channels to reality. If environmental events fall outside the range of sensitivity of the sensory channels, those events will not be experienced directly. It

may be possible to detect some of these events indirectly, using specialized instruments. Such instruments work in one of two ways. Some amplify physical energy, making weak signals strong enough to stimulate the senses. For example, a microscope can magnify objects otherwise too small to be seen by the naked eye. Other instruments convert energy that is *outside* the normal bounds of the senses into a form that is within those bounds. For instance, Geiger counters can warn about the presence of radioactivity, a form of energy that cannot be sensed directly. In either case, though, such instruments are being used to extend the reach of the sensory system.

It may be difficult to accept that your rich perceptual world encompasses only a small, restricted portion of the entire universe. Because one's conception of reality is so intimately determined by one's subjective experiences, it seems unnatural to distinguish between one's "perception of the world" and the "world itself." Yet to understand perception fully, you have to make this distinction. Perhaps a few examples will enable you to appreciate what we