

Contents

1 From Neurophysiology to Neuroscience: New Technologies and New Concepts in the Twentieth Century	1
François Clarac	
1.1 Nervous System Explorations from 1900 to 1950	2
1.2 New Scientific Developments and the Foundation of Neuroscience	5
1.3 Neuroscience in Progress: 1960–2000	7
1.4 Computational Neuroscience	11
1.5 History of “Animal Models”	11
References	16
2 Evolution of Nervous Systems and Brains	19
Gerhard Roth and Ursula Dicke	
2.1 Reconstruction of the Evolution of Nervous Systems and Brains	19
2.2 Organisms Without a Nervous System	20
2.3 Nervous Systems in Eumetazoans	21
2.4 Major Evolutionary Changes of the Vertebrate Brain	38
2.5 Brain and Intelligence	41
2.6 Convergence or “Deep Homologies”?	42
2.7 Summary – Major Trends in the Evolution of Nervous Systems and Brains	43
References	44
3 Ontogeny of the Vertebrate Nervous System	47
Salvador Martínez, Eduardo Puelles, and Diego Echevarria	
3.1 Induction and Regionalization of the Neural Plate: The Planar Map	47
3.2 Topologic and Topographic Patterning of the Early Brain: Dorsoventral (DV) Patterning and Anterior-Posterior (AP) Patterning	49
3.3 Regionalization of the Neural Tube	52
3.4 Genetic Regionalization According to Brain Subdivisions: The Importance of Secondary Organizers	53
3.5 Summary	60
References	61

4	Diseases	63
	Jean-Jacques Hauw, Marie-Anne Colle, and Danielle Seilhean	
4.1	Main Mechanisms of Cell Pathology in the Nervous System	63
4.2	Representative Diseases	66
	References	74
5	Neurophilosophy	75
	Georg Northoff	
5.1	Background: The History of Neurophilosophy	75
5.2	Empirical Neurophilosophy – Experimental Investigation of Philosophical Concepts	76
5.3	Theoretical Neurophilosophy – Methodology and Knowledge of the Linkage Between Brain Data and Philosophical Concepts	77
5.4	Practical Neurophilosophy – Neuroethics and the Relevance of Ethical Concerns in Neuroscience	78
5.5	Summary	79
	References	79
6	Cellular and Molecular Basis of Neural Function	81
	Herbert Zimmermann	
6.1	Cell Membranes	81
6.2	From Gene to Functional Protein	85
6.3	Membrane Transport	92
6.4	Cell Communication	94
6.5	Filamentous Cell Proteins Form the Cytoskeleton	101
6.6	Molecular Motors and Axonal Transport	103
6.7	Membrane Trafficking, Exocytosis, and Endocytosis	107
6.8	Summary	110
	References	111
	Recommended Textbooks	112
7	Electrical Activity in Neurons	113
	Veronica Egger and Dirk Feldmeyer	
7.1	Ion Channel Function: General Principles	114
7.2	Voltage-Gated Cation Channels	117
7.3	Chloride Channels	127
7.4	Resting Potential	128
7.5	Regenerative Activity: Na ⁺ and Ca ²⁺ Action Potentials	134
7.6	Conduction of Electricity in Neurons	137
7.7	Summary and Outlook	142
	References	142
8	The Synapse	145
	Christian Lüscher and Carl Petersen	
8.1	Phylogeny of the Synapse	146
8.2	Structure and Diversity of Synapses	146
8.3	Synaptic Release	148
8.4	Ligand-Gated Synaptic Membrane Channels for Glutamate	149
8.5	Ligand-Gated Synaptic Membrane Channels for GABA	151
8.6	Slow Synaptic Currents Mediated by G Protein-Coupled Receptors	152
8.7	Retrograde Signaling at Central Synapses	153

8.8	Electrical Synapses	153
8.9	Short-Term Synaptic Plasticity	155
8.10	Long-Term Synaptic Plasticity: Postsynaptic Forms	156
8.11	Long-Term Synaptic Plasticity: Presynaptic Forms	158
8.12	Structural Synaptic Plasticity	158
8.13	Synapses and Disease	159
8.14	Summary	160
	References	161
	Additional Readings	161
9	Biology and Function of Glial Cells	163
	Magdalena Götz	
9.1	Invertebrate Glia	164
9.2	Vertebrate Glia	168
9.3	Summary and Outlook	176
	References	176
10	The Autonomic Nervous System	179
	Wilfrid Jänig	
10.1	Neural and Neuroendocrine Regulation of Visceral Body Functions: An Overview	179
10.2	Organization of the Autonomic Nervous System in Mammals	180
10.3	Functional Autonomic Motor Pathways	183
10.4	Transmission of Signals in Peripheral Autonomic Pathways	186
10.5	The Enteric Nervous System	197
10.6	Central Organization of the Autonomic Nervous System: A Summary	199
10.7	The Peripheral Autonomic Nervous System in Non-Mammalian Vertebrates: A Comparative View	200
10.8	Regulation of Body Tissues in Invertebrates	205
	References	209
11	Neuropeptides and Peptide Hormones	213
	Dick R. Nässel and Dan Larhammar	
11.1	Neuropeptides, Peptide Hormones, and Their Receptors	214
11.2	Morphology and Function of Neurosecretory Cells and Peptidergic Neurons	215
11.3	Organization of Neuroendocrine and Peptidergic Systems in Invertebrates	217
11.4	Comparing Functional Roles of Some Neuropeptides and Peptide Hormones Across Phyla	226
11.5	Vertebrate Neuropeptides and Peptide Hormones	227
11.6	Neuropeptides as (Co)Transmitters in the Brain of Vertebrates	234
11.7	Summary	236
	References	237
	Further Readings	237
12	The Biological Function of Sensory Systems	239
	Rainer Mausfeld	
12.1	Key Terminology and Key Issues of General Sensory Physiology	240
12.2	Neurophysics and Neurobiology of Sensory Systems	241
12.3	Sensory Information Can Be Coded in Frequency Codes or in Temporal Codes	243

12.4	Gestalt-Filters for Complex Environmental Features Can Be Realized by Suitable Neural Networks	246
12.5	Behavioral Biology of Sensory Systems: Neuroethology and Comparative Sensory Physiology	247
12.6	Psychophysics and Perceptual Psychology.	247
	References	251
13	Olfaction	253
	C. Giovanni Galizia and Pierre-Marie Lledo	
13.1	The Theory of Olfactory Coding	253
13.2	Olfaction in Insects	256
13.3	Olfaction in Crustaceans	265
13.4	Olfaction in Nematodes	267
13.5	Olfaction in Other Invertebrates	268
13.6	Olfaction in Vertebrates	269
13.7	Summary	282
	References	283
14	Taste	285
	Wolfgang Meyerhof	
14.1	Taste Qualities and Taste Molecules	286
14.2	The Mammalian Gustatory System	287
14.3	The Insect Gustatory System	297
14.4	The Chemosensory System of <i>Caenorhabditis elegans</i>	299
14.5	Role of Taste in Feeding and Nutrition	301
	References	302
15	Thermosensation	303
	Carlos Belmonte Martínez and Elvira de la Peña García	
15.1	Influence of Temperature on Living Organisms	303
15.2	Temperature Sensing.	304
15.3	Thermotransduction Molecules	304
15.4	Thermoreceptor Cells	307
15.5	Temperature Detection in Ectotherms	308
15.6	Temperature Detection in Endotherms	310
15.7	Behavioral Responses to Thermosensory Information	315
	References	318
16	Mechanosensation	321
	Jörg T. Albert and Martin C. Göpfert	
16.1	A Mechanosensory System in a Nutshell: The Osmotic Shock Response of <i>E. Coli</i>	322
16.2	Mechanoelectrical Transduction – Ciliates and the Advent of Ion Selectivity and Specificity	322
16.3	Mechanoelectrical Transduction in Sensory Cells – Mechanisms and Genes	323
16.4	The Mammalian Somatosensory System	330
16.5	Central Processing of Mechanosensory Information – Converting Mechanosensory Information into Behavioral Responses	332
	References	334

17	Auditory Systems	337
	Günter Ehret and Martin C. Göpfert	
	17.1 The Physics of the Stimulus	337
	17.2 Mammals.	338
	17.3 Birds, Reptiles, and Amphibians	353
	17.4 Fish	355
	17.5 Insects	358
	17.6 Other Invertebrates	361
	References	361
18	Vision	363
	Jutta Kretzberg and Udo Ernst	
	18.1 The Physics of the Stimulus	363
	18.2 Mammals: Vision in Primates.	365
	18.3 Specific Differences in Other Vertebrates.	395
	18.4 Insects	398
	18.5 Specific Differences in Other Invertebrates	402
	18.6 Summary.	405
	References	406
19	Electroreception	409
	Gerhard von der Emde	
	19.1 Electroreception in Nature	409
	19.2 Electroreception in Mammals.	410
	19.3 Passive Electrolocation in Fishes	410
	19.4 Strongly Electric Fishes	414
	19.5 Weakly Electric Fish	414
	References	424
20	The Magnetic Senses	427
	Henrik Mouritsen	
	20.1 Magnetic Fields.	427
	20.2 The Earth's Magnetic Field.	428
	20.3 How Can We Study the Influence of the Earth's Magnetic Field on Animal Behavior?.	429
	20.4 Interactions with Other Cues	434
	20.5 How Can Animals Possibly Sense the Geomagnetic Field?.	435
	20.6 Irreproducible Results and the Urgent Need for Independent Replication	440
	20.7 Where Do We Go from Here?.	440
	References	442
21	Pain and Nociception	445
	Maria P. Abbracchio and Angelo M. Reggiani	
	21.1 The Physics of the Stimulus	446
	21.2 Pain in Humans	446
	21.3 Pain in Animals Other than Mammals	455
	21.4 Pain Therapy in Humans: Current and Future	457
	References	459
	Further Readings	459

22	Muscles and Motility	461
	Ingo Morano	
22.1	Control of Muscle Function in the Vertebrate Body	461
22.2	Structure of the Vertebrate Skeletal Muscles	463
22.3	Energetics of Muscle Contraction	466
22.4	Excitation-Contraction Coupling	468
22.5	Skeletal Muscle Fiber Types and Regulation of Force Generation	469
22.6	Skeletal Muscle Fatigue	471
22.7	The Musculature of the Mammalian Heart	472
22.8	The Mammalian Smooth Musculature	474
22.9	Muscles in Invertebrates	475
	References	477
23	Motor Control	479
	Hans-Joachim Pflüger and Keith Sillar	
23.1	Introduction	479
23.2	The Neuromuscular Basics	480
23.3	Comparison Between Invertebrate and Vertebrate Skeletal Muscles	482
23.4	Common Principles in the Generation and Control of Motor Patterns in Vertebrates and Invertebrates	487
23.5	Sensory Feedback Together with Central Pattern Generators Produce Appropriate Motor Behavior	490
23.6	Decision Making for a Particular Motor Pattern	511
23.7	Summary	522
	References	523
24	The Neural Bases of Emotions	525
	Tamara B. Franklin and Isabelle M. Mansuy	
24.1	Theories of Emotion	525
24.2	Neuroanatomy of Emotion	528
24.3	Stress	532
24.4	Disorders of Emotional State: Depression and Anxiety Disorders	535
24.5	Fear Learning and Memory	543
24.6	Motivation and Emotion	549
24.7	Summary and Outlook	550
	References	551
25	Experience-Dependent Plasticity in the Central Nervous System	553
	José Fernando Maya-Vetencourt and Matteo Caleo	
25.1	Genetic Factors and Sensory Experience Sculpt the Nervous System Architecture	554
25.2	Plasticity of the Nervous System is High During Critical Periods but Decreases Thereafter	555
25.3	Experience-Dependent Forms of Plasticity in the Visual System	556

25.4	Structural and Functional Mechanisms that Control Critical Period Plasticity in the Visual System	559
25.5	Hebbian Plasticity and NMDA-Type Glutamate Receptors	562
25.6	Long-Term Potentiation (LTP) and Long-Term Depression (LTD)	562
25.7	Homeostatic Plasticity	563
25.8	Structural Underpinnings of Experience-Dependent Plasticity	564
25.9	Short Noncoding RNAs and the Regulation of Experience-Dependent Plasticity	565
25.10	The Process of Plasticity Reactivation in the Adult Visual System	565
25.11	Early Experience Influences Rodents' Behavior by Modifications of Chromatin Structure	566
25.12	Experience-Dependent Plasticity in the Auditory System	567
25.13	Experience-Dependent Plasticity in the Somatosensory System	572
25.14	Plasticity in the Olfactory System	574
25.15	Cross-Modal Developmental Plasticity	574
25.16	Summary	575
	References	575
26	Cellular Correlates of Learning and Memory	577
	Martin Korte	
26.1	Forms of Learning	578
26.2	Model Systems	580
26.3	Nonassociative Learning in Simple Organisms	580
26.4	Associativity and Classical Conditioning in Simple Organisms	583
26.5	Learning and Memory in the Vertebrate Brain	588
26.6	Long-Term Maintenance of Synaptic Plasticity	601
26.7	Summary	607
	References	608
27	Circadian Timing	609
	François Rouyer	
27.1	Circadian Clocks	610
27.2	Molecular Mechanisms of Circadian Oscillators	614
27.3	Neural Organization of the Fly Clock	617
27.4	Neural Organization of the Mammalian Clock	622
	References	626
28	Learning, Memory, and Cognition: Animal Perspectives	629
	Randolf Menzel	
28.1	Cognition: Definition	629
28.2	Innate and Learned Behavior	630
28.3	Learning: Elemental Forms of Associative Learning	631
28.4	Nonelemental Forms of Associative Learning	639
28.5	Working Memory: Planning and Decision Making	650
28.6	Animal Thinking: The Basics	652
	References	653

29 Primate Social Intelligence	655
Julia Fischer	
29.1 Brain Size Evolution	655
29.2 Primate Social Relationships	656
29.3 Social Knowledge	658
29.4 Social Learning	659
29.5 Theory of Mind	661
29.6 Primate Communication	665
29.7 Summary	667
References	668
30 Computational Neuroscience: Capturing the Essence	671
Shaul Druckmann, Albert Gidon, and Idan Segev	
30.1 Neurons: Input-Output Plastic Devices	671
30.2 Computation in Neuronal Networks	685
30.3 Summary	692
References	693
Index	695