Advances in Metabolic Mapping Techniques for Brain Imaging of Behavioral and Learning Functions

NATO ASI Series

Advanced Science Institutes Series

A Series presenting the results of activities sponsored by the NATO Science Committee, which aims at the dissemination of advanced scientific and technological knowledge, with a view to strengthening links between scientific communities.

The Series is published by an international board of publishers in conjunction with the NATO Scientific Affairs Division

A Life Sciences

Plenum Publishing Corporation
London and New York

B Physics

**C Mathematical
and Physical Sciences**

Kluwer Academic Publishers
Dordrecht, Boston and London

D Behavioural and Social Sciences

E Applied Sciences

F Computer and Systems Sciences

Springer-Verlag

G Ecological Sciences

Berlin, Heidelberg, New York, London,

H Cell Biology

Paris and Tokyo

I Global Environmental Change

NATO-PCO-DATA BASE

The electronic index to the NATO ASI Series provides full bibliographical references (with keywords and/or abstracts) to more than 30000 contributions from international scientists published in all sections of the NATO ASI Series.

Access to the NATO-PCO-DATA BASE is possible in two ways:

- via online FILE 128 (NATO-PCO-DATA BASE) hosted by ESRIN,
Via Galileo Galilei, I-00044 Frascati, Italy.
- via CD-ROM "NATO-PCO-DATA BASE" with user-friendly retrieval software in English, French and German (© WTV GmbH and DATAWARE Technologies Inc. 1989).

The CD-ROM can be ordered through any member of the Board of Publishers or through NATO-PCO, Overijse, Belgium.

Advances in Metabolic Mapping Techniques for Brain Imaging of Behavioral and Learning Functions

edited by

F. Gonzalez-Lima

Department of Psychology,
University of Texas, Austin, TX, U.S.A.

Th. Finkenstädt

Schering AG, Berlin, Germany

and

H. Scheich

Institute for Zoology,
Technical University,
Darmstadt, Germany

Kluwer Academic Publishers

Dordrecht / Boston / London

Published in cooperation with NATO Scientific Affairs Division

Proceedings of the NATO Advanced Research Workshop on
Advances in Metabolic Mapping Techniques for Brain Imaging of Behavioral and
Learning Functions
Austin, Texas, U.S.A.
7–9 November 1991

Library of Congress Cataloging-in-Publication Data

ISBN-13: 978-94-010-5202-3 e-ISBN-13: 978-94-011-2712-7
DOI:10.1007/978-94-011-2712-7

Published by Kluwer Academic Publishers,
P.O. Box 17, 3300 AA Dordrecht, The Netherlands.

Kluwer Academic Publishers incorporates the publishing programmes of
D. Reidel, Martinus Nijhoff, Dr W. Junk and MTP Press.

Sold and distributed in the U.S.A. and Canada
by Kluwer Academic Publishers,
101 Philip Drive, Norwell, MA 02061, U.S.A.

In all other countries, sold and distributed
by Kluwer Academic Publishers Group,
P.O. Box 322, 3300 AH Dordrecht, The Netherlands.

All Rights Reserved

© 1992 Kluwer Academic Publishers

No part of the material protected by this copyright notice may be reproduced or
utilized in any form or by any means, electronic or mechanical, including photo-
copying, recording or by any information storage and retrieval system, without written
permission from the copyright owner.

Dedicated in honor of
Dr. Louis Sokoloff and colleagues
for leading the way,
on the occasion of the fifteenth
anniversary of the introduction of
the 2-deoxyglucose method

Contents

Part I: Techniques

Imaging Techniques in Studies of Neural Functions

L. SOKOLOFF

1. Introduction	1
2. Local Cerebral Blood Flow	2
3. Local Cerebral Glucose Utilization	8
3.1. Theoretical Basis of Radioactive Deoxyglucose Method	8
3.2. Considerations in Design of Procedure	11
3.3. Experimental Procedure	16
3.4. Local Rates of Cerebral Glucose Utilization	17
3.5. The [^{18}F]Fluorodeoxyglucose Technique	17
3.6. Metabolic Mapping of Local Functional Activity	18
4. Local Cerebral Protein Synthesis	21
4.1. Theory	21
4.2. Determination of λ_i	25
4.3. Local Rates of Protein Synthesis in the Conscious Rat Brain	27
4.4. Applications of Autoradiographic L-[1- ^{14}C]Leucine Method	27
5. Miscellaneous Imaging Methods	31
6. References	31

Brain Imaging of Auditory Learning Functions in Rats: Studies with Fluorodeoxyglucose Autoradiography and Cytochrome Oxidase Histochemistry

F. GONZALEZ-LIMA

1. Introduction	39
1.1. Brain Imaging with Metabolic Mapping Techniques	39
1.2. Neuronal Activity in Sensory Systems is Modified by Learning	41
1.3. Metabolic Mapping Studies show Learning-Related Modifications in the Activity of the Auditory System	41
2. Principles of Fluorodeoxyglucose Autoradiography and their Applications for Neuroimaging of Learning Functions	44
2.1. Goals for FDG Autoradiographic Experiments	44
2.2. Transport and Uptake of FDG as a Glucose Analog	46
2.3. Tracer Specific Activity and Testing Conditions	48
2.4. Tissue Processing for FDG Autoradiography	50
2.5. Quantitative Analysis of FDG Autoradiographs	53

2.6. Procedure for FDG Quantitative Autoradiography	56
3. Application of FDG to the Study of Behavioral Habituation to an Auditory Stimulus	59
3.1. Short and Long-Term Habituation of the Acoustic Startle Reflex	59
3.2. Experimental Design and Methods	60
3.3. Effects on the Auditory System	60
3.4. Effects Outside the Auditory System	61
3.5. Model of the Neural Circuitry Related to Long-Term Habituation of the Acoustic Startle Reflex	68
4. Application of FDG to the Study of Differential Conditioning of Auditory Stimuli	71
4.1. Neural Effects of Sounds Differentially Associated with Appetitive and Aversive Unconditioned Stimuli	71
4.2. Experimental Design and Methods	73
4.3. Effects on the Auditory System	75
4.4. Effects Outside the Auditory System	80
4.5. Model of the Neural Circuitry Related to Differential Conditioning of Auditory Stimuli	80
5. Principles of Cytochrome Oxidase Histochemistry and their Applications for Neuroimaging of Learning Functions	85
5.1. Goals for CO Histochemical Experiments	85
5.2. The use of CO as an Endogenous Marker for Neuronal Function	87
5.3. CO Enzymology and Quantitative Histochemistry	88
5.4. Procedure for CO Quantitative Histochemistry	91
6. Application of CO Histochemistry to the Study of Learning Functions	94
6.1. Interassay Variability and Linearity for Group Comparisons	94
6.2. Learning-Related Increase in Metabolic Capacity	97
7. Conclusions	99
7.1. Application of FDG Autoradiography to Long-Term Habituation Revealed the Functional Brain Circuitry Mediating this Simple Form of Learning	99
7.2. Application of FDG Autoradiography to Differential Conditioning Revealed the Functional Brain Circuitry Mediating this Form of Discrimination Learning	99
7.3. Application of CO Histochemistry Revealed Long-Lasting Modifications in Metabolic Capacity Related to Chronic Learning	100
7.4. Learning-Related Changes are Distributed in Neural Systems with Specific Functional Contributions to Modify Behavior	100
8. Acknowledgements	100
9. References	101

**Mapping Sensorimotor Pathways in Rat Brain Using 2-Deoxyglucose
Autoradiography and C-Fos Immunocytochemistry**

FRANK R. SHARP and STEPHEN M. SAGAR

1. Introduction-2-DG Studies of Thalamus	111
2. 2-DG Methods-Whisker Stimulation Following Cortical Lesions	113
3. Conclusions of 2-DG Studies	115
4. Introduction- c-fos Studies	117
5. Methods-Cortical Stimulation with c-fos and 2-DG	117
6. Results- c-fos and 2-DG	118
7. Conclusions	120
8. Comments on Quantitation of 2-DG and c-fos Studies	121
9. Acknowledgements	123
10. References	123

**Brain Metabolic Mapping and Behavior: Assessing the Effects of Early
Developmental Experiences in Adult Animals**

JOSÉ N. NOBREGA

1. General Introduction	125
1.1. General Methodological Aspects	126
2. Study I: ¹⁴ C-2-DG Autoradiography Under Normal vs. Challenge Conditions: Effects of Neonatal 6-OHDA Lesions and Rearing Environment	128
2.1. Methods	129
2.2. Results	132
2.3. Discussion	135
3. Study II: Effects of Prenatal Cocaine Exposure on Regional Brain Glucose Metabolism and Cytochrome Oxidase Histochemistry	135
3.1. Methods	138
3.2. Results	140
3.3. Discussion	143
4. General Conclusions	145
5. Acknowledgements	145
6. References	146

**High Resolution Autoradiographic Imaging of Brain Activity Patterns With 2-
Deoxyglucose: Regional Topographic and Cellular Analysis**

GARY E. DUNCAN

1. Introduction	152
2. Methods and Examples of Results	152
2.1. Animal Preparation for Injection of 2-DG	152
2.2. Improvement of Regional Topographic Resolution in 2-DG Studies	153
2.3. Cellular Resolution in 2-DG Studies	155

3. Consideration of the Time Course of 2-DG Studies	162
4. Quantitative Considerations in 5 Minutes 2-DG Studies	167
5. Summary and Conclusions	169
6. Acknowledgements	170
7. References	171

Metabolic Mapping in the Hippocampus. Patterns of (^{14}C)2-Deoxyglucose Uptake Within Different Fields of the Hippocampal Slice

P. ROOM, F.A. DIJCKS and G.S.F. RUIGT

1. Introduction	174
2. Material and Methods	175
2.1. Tissue Preparation	175
2.2. Electrophysiology	175
2.3. [^{14}C]2-Deoxyglucose Incubation	175
2.4. Potassium Stimulation	176
2.5. Histology	176
2.6. Densitometric Analysis	176
3. Results	177
3.1. Comparison with Previous <i>in vivo</i> Results	177
3.2. Potassium Stimulation	178
4. Discussion	181
4.1. Potassium Stimulation	185
5. Acknowledgements	186
6. References	186

Covariance Analysis of Functional Interactions in the Brain Using Metabolic and Blood Flow Data

BARRY HORWITZ, TIMOTHY T. SONCRANT, and JAMES V. HAXBY

1. Introduction	189
2. Methods	192
3. Examples of Correlational Analyses	195
3.1. Nucleus Basalis Magnocellularis Lesions in the Rat	195
3.2. Obsessive-Compulsive Disorder	197
3.3. Object and Spatial Vision in Humans	199
4. What are the Neurobiological Substrates of Interregional Correlations?	203
5. Brain Network Modeling of Metabolic Data	208
5.1. The Model	208
5.2. Examples of Simulations	209
5.3. Data-Fitting and Combinations of Neural Models	211
6. Acknowledgements	212
7. References	212

The Application of Structural Modeling to Metabolic Mapping of Functional Neural Systems

A.R. McINTOSH and F. GONZALEZ-LIMA

1. Introduction	219
2. General Method	220
2.1. Building a Model	224
2.2. Preparation of Data	226
2.3. Running the Analysis	228
2.4. Stacked Models	230
2.5. Theoretical Interpretation of the Model	231
3. Auditory System Model of Long-Term Habituation	233
3.1. Results	234
3.2. Discussion of Auditory System Models	238
4. Visual System Model of the Effects of Patterned Light and Footshock	239
4.1. Results	241
4.2. Discussion of Visual System Models	245
5. General Discussion	247
5.1. Considerations and Caveats	248
5.2. Other Methods of Data Quantification	249
5.3. Concluding Remarks	251
6. References	252

**Part II:
Applications**

A 2-DG Analysis of the Effects of Monocular Deprivation on the Rat Visual System

R.M. COOPER, G.A. THURLOW, A. JEEVA, and A. GAFKA

1. Introduction	259
2. General Methods	261
2.1. Subjects	261
2.2. 2-DG Procedure	261
3. Results and Discussion	268
3.1. Six-Week Infant MD; Test: Binocular Exposure to Gratings	268
3.2. Six-Week Infant MD; Test: Dark Box	270
3.3. Six-Week Juvenile and Adult MD; Test: Binocular Exposure to Gratings	271
3.4. Six-Week Infant MD; Test: Binocular Exposure to Diffuse Light	273
3.5. Two- to Nine-Week Normal; Test: Monocular Exposure to Gratings or Flashing-Diffuse Light	275
4. Conclusions	277
5. Acknowledgements	278
6. References	278

Development of Sound Representation in the Auditory Cortex of Tree Shrews (Tupaia Belangeri): A [^{14}C]-2-DG Study

H. BINZ, E. ZIMMERMANN and H. RAHMANN

1. Introduction	281
2. Material and Methods	282
2.1. Subjects and Housing	282
2.2. 2-DG Application	283
2.3. Acoustic Stimulation	283
2.4. Tissue Preparation and Autoradiography	284
2.5. Histological Identification of Labelled Regions	285
2.6. Data Analysis and Documentation of Results	286
3. Results	287
3.1. Effect of Different Sound Patterns (BBN, HFS, LFS, SC) on 2-DG Uptake in Auditory Cortex of Adult Tree Shrews	287
3.2. Effect of Different Sound Patterns (BBN, SC) on 2-DG Uptake in the Auditory Cortex of Developing Tree Shrews	289
4. Conclusions	293
5. References	294

Integration of Circadian and Visual Function in Mammals and Birds: Brain Imaging and the Role of Melatonin in Biological Clock Regulation

VINCENT M. CASSONE, DAVID S. BROOKS, DONALD B. HODGES
TERESA A. KELM, LU JUN and WADE S. WARREN

1. Introduction	299
1.1. The Avian Circadian Clock is a Multi-Component System	300
1.2. Mammalian Circadian Rhythmicity and the Suprachiasmatic Nucleus	302
2. Methodology	303
2.1. Circadian Rhythm Research	303
2.2. 2-Deoxyglucose Technique	304
2.3. <i>In Vitro</i> 2- ^{125}I Iodomelatonin Binding	305
2.3. Image Representation	307
3. Melatonin and the Rat Circadian System	307
3.1. Effects of Melatonin on Rat SCN 2-Deoxyglucose Uptake	307
3.2. 2- ^{125}I Iodomelatonin Binding in the Rodent Brain	307
4. Sites of Melatonin Action in the Avian Brain	309
4.1. Circadian Variation of 2-Deoxyglucose Uptake in the Brain of the House Sparrow	309
4.2. Effect of Exogenous Melatonin on Cerebral 2-Deoxyglucose Uptake in the House Sparrow	309
4.3. 2- ^{125}I Iodomelatonin Binding within the Avian Brain	310
5. Conclusions	313
6. Literature Cited	314

Functional Correlates of Acute Prolonged Pain in the Rat Central Nervous System:**2-DG Studies**

C.A. PORRO and M. CAVAZZUTI

1. Introduction	319
2. Methods	321
2.1. The Formalin Test	321
2.2. Quantitative 2-DG Studies	322
2.3. Semi-Quantitative 2-DG Studies	324
3. Results and Discussion	325
3.1. Animal Behavior	325
3.2. Physiological Variables	326
3.3. Glucose Metabolism	328
4. Conclusions	337
5. Acknowledgements	337
6. References	337

Brain Systems Involved in Depressed Behaviors: Corroboration from Different Metabolic Mapping Studies.

S. CALDECOTT-HAZARD and A.D. WEISSMAN

1. Introduction	343
2. Methods	344
3. Results	347
4. Mapping Studies of Reward and Arousal	352
5. Mapping Studies of Reduced Locomotion	358
6. Conclusions	361
7. References	361

2-DG and Neuroethology: Metabolic Mapping of Brain Activity During Species-Typical Sexual and Aggressive Behaviors

DAVID CREWS

1. Introduction	367
2. Reptiles as a Source of Model Systems in Behavioral Neuroscience	368
3. Brain Imaging During Sexual and Agonistic Behavior in Three Reptile Animal Models	369
3.1. Red-Sided Garter Snake	369
3.2. Green Anole Lizard	374
3.3. Whiptail Lizard	378
4. Conclusions	381
5. Acknowledgements	383
6. References	384

Investigations into Time-Dependent Metabolic Changes During Memory Processing in the Mouse Brain Using (¹⁴C)-Deoxyglucose and (¹⁴C)-Glucose

C. DESTRADE, C. MESSIER, B. BONTEMPI, J. SIF, and R. JAFFARD

1. Introduction	389
1.1. The Concept of Memory Processing	389
1.2. The Use of 2-DG to Study Learning and Memory Processes	390
2. Materials and Methods	391
2.1. Subjects	391
2.2. Surgery	391
2.3. Procedure for Injection of the Tracer	392
2.4. Processing of Brain Tissue	393
2.5. Densitometric Analysis of Autoradiographs: The Semi-Quantitative Method	393
2.6. The use of (¹⁴ C)-Glucose to Study Short-Time Frames	394
2.7. Behavioral Tasks	394
2.8. Experimental Protocols	397
3. Results	399
3.1. Time-Dependent Sequential Increases in 2-DG Uptake During Memory Consolidation of the Bar-Pressing Task	399
3.2. Time-Dependent (¹⁴ C)-Glucose Uptake Patterns During Memory Processing of Spatial Discrimination Testing in Radial Maze.	402
3.3. General Discussion	404
4. Conclusions	404
5. Acknowledgements	405
6. References	405

Localization of Learning-Related Metabolic Changes in Brain Structures of Common Toads: A 2-DG-Study

Th. FINKENSTÄDT and J.-P. EWERT

1. Introduction	410
2. Methods	410
2.1. Training Procedure	410
2.2. Mapping of Brain Activity with 2-DG, Technical Questions	414
3. Results	418
3.1. Behavioral Effects of Visual Conditioning on Prey-Predator Discrimination	418
3.2. Comparison of 2-DG Uptake on Naive and Visually Monocular and Binocular Conditioned Toads	419
3.3. Brain Lesions	421
3.4. Summary of Olfactory Learning Experiments in Toads with 2-DG	423
3.5. Summary of Extracellular Single Cell Recording	426

3.6. Summary of Visual Long-Term Habituation Experiments with 2-DG in Toads	427
3.7. Summary of Results of 2-DG Experiments in MS222 Anesthetized Toads	428
3.8. Summary of Results of 2-DG Experiments in Electrically RET Stimulated Toads	429
3.9. Summary of Results of 2-DG Experiments, Combining MS222 Anesthesia and Electrical RET Stimulation in Toads	430
4. Discussion	431
4.1. Associative Conditioning versus Extinction Learning	431
4.2. Usefulness of the Selected 2-DG Method in Combination with other Techniques for the Questions, Tackled in the Described Experiments.	431
4.3. Physical Properties of the Stimulus and its Learned Motivational Significance	434
4.4. Changes of Metabolic Activity in the Central Visual Pathway	435
4.5. Changes of 2-DG Uptake Patterns in Non-Visual Forebrain Areas of Trained Toads	436
5. Conclusions	438
6. References	440

Learning-Related Plasticity of Gerbil Auditory Cortex: Feature Maps versus Meaning Maps

H. SCHEICH, C. SIMONIS, F. OHL, H. THOMAS, and J. TILLEIN

1. Introduction	447
2. Basic Functional Organization of Auditory Cortex: Electrophysiology	449
3. Basic Functional Organization of Auditory Cortex: Deoxyglucose Labeling	451
4. Learning-Induced Changes of Fluoro-2-Deoxyglucose Uptake	457
5. Electrophysiological Changes after Classical Conditioning	459
6. Discussion	466
7. Literature	469

**Part III:
Discussions**

Discussions on Advances in Metabolic Mapping Techniques	477-493
--	----------------

Edited by F. GONZALEZ-LIMA and A.R. McINTOSH

Participants: H. SCHEICH (Chair), F.R. SHARP, B. HORWITZ, L. SOKOLOFF, F. GONZALEZ-LIMA, M. KADEKARO, G.E. DUNCAN, A. FILLER, M.J. TRAMO, R.M. COOPER, L.L. BROWN, F.J. HELMSTETTER, P. ROOM

Discussions on Brain Imaging of Behavioral Functions 494-508

Edited by Th. FINKENSTÄDT (Chair), F. GONZALEZ-LIMA, and A.R. McINTOSH

Participants: Th. FINKENSTÄDT, F. GONZALEZ-LIMA, D.P. CREWS, F.R. SHARP,
L. SOKOLOFF, S.P. ROSE, A. AMSEL, H. SCHEICH, L.L. BROWN, V.
CASSONE, S. CALDECOTT-HAZARD, P.T. FOX, B. HORWITZ, J.N.
NOBREGA

Discussions on Brain Imaging of Learning Functions 509-522

Edited by F. GONZALEZ-LIMA (Chair)

Participants: A. AMSEL, J. L. McGAUGH, F. GONZALEZ-LIMA, Th.
FINKENSTÄDT, D. P. CREWS, M. J. TRAMO, R. M. COOPER, H.
SCHEICH, L. SOKOLOFF, B. HORWITZ

Subject Index 523-527

Preface

This book is the result of the NATO Advanced Research Workshop on “Advances in Metabolic Mapping Techniques for Brain Imaging of Behavioral and Learning Functions”, held in Austin, Texas on November 7-9, 1991. This first international workshop on metabolic mapping techniques applied to behavioral studies was dedicated in honor of Louis Sokoloff because, in our opinion, the 2-deoxyglucose method introduced by Sokoloff and his colleagues in 1977 is the most significant breakthrough for the investigation of “a whole brain at work” since Berger’s recordings of the human electroencephalograph in 1929. Electroencephalography led to the development of electrophysiological techniques such as evoked potentials, single unit recordings, and recently patch clamping, that have made enormous contributions to brain research. As already suggested by its application to the human brain, i.e. by the (^{18}F)fluorodeoxyglucose technique together with positron emission tomography, the 2-deoxyglucose method may also develop into various specialized techniques, all allowing an integral view of brain activity.

The potential impact of these metabolic mapping techniques for elucidating brain functions related to behavior is enormous. Researchers will be able to visualize brain systems involved in specific functions, to study complex behavior, and to map the complex circuitry underlying the various forms of learning and memory. However, in spite of the great potential of the new imaging techniques, relatively few neuroscientists are using this approach to study brain functions related to behavior. There is a need to review contemporary applications of these methods in behavioral neuroscience, and to formulate recommendations for future research in this area.

The aim of this book is to review state-of-the-art applications of a new generation of cell metabolic mapping techniques capable of visually imaging brain functions related to learning and behavior. A major goal of this book is to serve as a “technical handbook” of reference to behavioral neuroscientists interested in implementing these techniques. The unifying theme throughout the book is a focus on behavioral applications of autoradiographic techniques based on the use of radiolabeled glucose analogs, especially 2-deoxyglucose and fluorodeoxyglucose. The book is made up of 20 chapters, divided into three major parts dealing primarily with techniques, applications, and discussions respectively. PART I deals mainly with methodological approaches and leads off with the contribution of Dr. Sokoloff, which provides an overview of imaging techniques and the foundations for measurement of cerebral blood flow, glucose utilization, and protein synthesis. Other contributions discuss mapping techniques based on fluorodeoxyglucose autoradiography, histochemical staining of endogenous metabolic markers such as cytochrome oxidase, immunocytochemistry for expression of c-fos protein, and cellular resolution autoradiography. The section concludes with presentations of computational modeling techniques that take advantage of brain imaging data to study the interactions of neural structures at the systems level. PART II demonstrates some of the neural systems and behavioral phenomena that have been studied using these mapping techniques, especially 2-deoxyglucose. Chapters in this section deal with visual, auditory

and pain perception, circadian rhythms, depressed behavior, sexual and aggressive behavior and learning and memory. The wide scope of preparations that have used brain mapping should provide with some sense of the versatility and tremendous potential of these techniques. In PART III, the summarized proceedings from three discussion panels that were conducted for the workshop appear as edited chapters at the end of the book. The participants are listed in order of appearance in the discussions.

The research findings gathered in this area were comprehensively reviewed, and guidelines for future research were formulated. There was also a need to address methodological issues important for application and interpretation of these new techniques in intact behaving animals. For example, issues include the units of measurements based on procedures other than quantitative autoradiography, and the interpretation of the new findings in relation to results provided by the more traditional neuroscience methodologies. Another feature of the book is that examples of applications of these new techniques are not limited to one animal species, but cover a broader range of vertebrates with unique behavioral capacities. This is expected to have a long-lasting impact on the field for two other reasons. First, it contains technical considerations of practical utility for established and new scientists in this burgeoning field. Furthermore, conceptual content dealing with the findings and interpretations obtained by the recent applications of these mapping techniques to behavioral brain research are discussed thoroughly. This book is the first one on this topic — brain research on learning and behavioral functions using the new metabolic mapping techniques.

To aid the reader in fully benefiting from this book, the table that appears below can be used to locate chapters which address different issues surrounding the use of metabolic mapping. For each chapter, a list is provided as to the main brain mapping technique that is presented, the behavioral functions and/or system studied, and species studied.

CHAPTER	TECHNIQUE	BEHAVIOR/SYSTEM	SPECIES
Sokoloff	2-Deoxyglucose, Cerebral blood flow, Protein synthesis	Resting metabolism, Neural regeneration, Visual system	Rat Cat Monkey
Gonzalez-Lima	[¹⁴ C]Fluorodeoxyglucose, Cytochrome oxidase	Habituation, Pavlovian conditioning, Differential conditioning, Auditory system	Rat
Sharp & Sagar	2-Deoxyglucose, c-fos	Sensorimotor coordination, Lesions/regeneration, Somatosensory system Motor system	Rat

CHAPTER	TECHNIQUE	BEHAVIOR/SYSTEM	SPECIES
Nobrega	2-Deoxyglucose, Cytochrome oxidase	Developmental experience, Enriched environment, Perinatal drug exposure	Rat
Duncan	Cellular resolution [³ H]2-Deoxyglucose, [¹⁴ C]Glucose	Swimming stress, Hippocampus	Rat
Room, Dijcks & Ruigt	In Vitro 2-Deoxyglucose	Hippocampal slice, Electrical/Chemical stimulation	Rat
Horwitz, Soncrant & Haxby	Correlational analyses, Cerebral blood flow, [¹⁸ F]Fluorodeoxyglucose, Positron emission tomography	Obsessive-Compulsive disorder, Basal forebrain, Visual perception Visual system	Human, Rat
McIntosh & Gonzalez- Lima	Structural modeling, 2-Deoxyglucose	Habituation, Arousal, Auditory system, Visual system	Rat
Cooper et al.	2-Deoxyglucose	Developmental experience, Visual system	Rat
Binz, Zimmerman & Rahmann	2-Deoxyglucose	Development, Acoustic communication Auditory system	Prosimians
Cassone et al.	2-Deoxyglucose, [¹²⁵ I]-Iodomelatonin	Circadian rhythms Hormonal control	Rat Bird
Porro & Cavazzuti	2-Deoxyglucose	Pain perception	Rat
Caldecott-Hazard & Weissman	2-Deoxyglucose	Depressed behavior, Reward and arousal	Rat
Crews	2-Deoxyglucose	Sexual and agonistic behavior	Reptiles
Destrade et al.	2-Deoxyglucose, [¹⁴ C]Glucose	Memory consolidation	Mouse
Finkenzstadt & Ewert	2-Deoxyglucose	Visual conditioning Olfactory conditioning, Anesthesia, Arousal	Toad
Scheich et al.	[¹⁴ C]Fluorodeoxyglucose	Aversive conditioning, Auditory cortex	Gerbil

The workshop was sponsored by the North Atlantic Treaty Organization under grant NATO910370, the National Science Foundation, under grant BNS9109098, and by contributions from Schering AG-Berlin, American Radiolabeled Chemicals, and Sandoz Pharmaceuticals.

I thank Dr. Erika M. Gonzalez-Lima and Anthony R. McIntosh for their assistance in the local coordination of the meeting, the co-organizers Drs. Thomas Finkenstädt and Henning Scheich, and the honored speaker Dr. Louis Sokoloff for their support. I express my special gratitude to my doctoral students, Anthony R. McIntosh, Amy Cada, and Dirk Jones, who helped me with all aspects involved in this project. The collaboration of all participants contributed greatly toward a successful workshop and fast publication of the proceedings. I am indebted to all of them for their generous and valuable contributions. I hope that this work will contribute to the advance of the new field of brain imaging of behavioral functions, by helping to start developing research strategies to clarify the role of the brain in translating activity patterns into behavior and memories.

Austin, Summer 1992

F. Gonzalez-Lima

Dr. Louis Sokoloff with the workshop organizers, Dr. H. Scheich to the left and Dr. F. Gonzalez-Lima and Dr. Th. Finkenstädt to the right.

Contributors

H. Binz, Institute of Zoology, University of Stuttgart-Hohenheim, Garbenstr. 30, 7000 Stuttgart 70, *Germany*

B. Bontempi, Laboratoire de Neurosciences comportementales et cognitives, URA CNRS 339, Université de Bordeaux I, Avenue des Facultés, 33405 Talence Cedex, *France*

David S. Brooks, Department of Biology, Texas A&M University, College Station, TX 77843, *USA*

S. Caldecott-Hazard, Center for Psychiatry, Florida Hospital, Orlando, FL 32803, *USA*

Vincent Cassone, Department of Biology, Texas A&M University, College Station, TX 77843, *USA*

M. Cavazzuti, Institute of Human Physiology and Neurology, University of Modena, Via Campi 287, 41100 Modena, *Italy*

R. M. Cooper, Department of Psychology, University of Calgary, 2500 University Drive N.W., Calgary, Alberta T2N 1N4, *Canada*

David Crews, Institute of Reproductive Biology, Departments of Zoology and Psychology, University of Texas, Austin, TX 78712, *USA*

Claude Destrade, Laboratoire de Neurosciences comportementales et cognitives, URA CNRS 339, Université de Bordeaux I, Avenue des Facultés, 33405 Talence Cedex, *France*

F. A. Dijcks, Department of CNS-Pharmacology, Organon International B.V., 5340 BH Oss, *The Netherlands*

Gary E. Duncan, Brain and Development Research Center, Departments of Cell Biology and Anatomy and Psychiatry, CB #7090, University of North Carolina, Chapel Hill, NC 27599, *USA*

J.-P. Ewert, Department Neuroethology, University Kassel, D-3500 Kassel, *Germany*

Th. Finkenstädt, Schering AG, 1000 Berlin 65, *Germany*

A. Gafka, Department of Psychology, University of Calgary, 2500 University Drive N.W., Calgary, Alberta T2N 1N4, *Canada*

F. Gonzalez-Lima, Department of Psychology and Institute for Neuroscience, University of Texas, Austin, TX 78712, *USA*

James V. Haxby, Laboratory of Neurosciences, National Institute of Aging, National Institutes of Health, Bldg. 10 Rm. 6C414, Bethesda, MD 20892, *USA*

Donald B. Hodges, Department of Biology, Texas A&M University, College Station, TX 77843, *USA*

Barry Horwitz, Laboratory of Neurosciences, National Institute of Aging, National Institutes of Health, Bldg. 10 Rm. 6C414, Bethesda, MD 20892, *USA*

R. Jaffard, Laboratoire de Neurosciences comportementales et cognitives, URA CNRS 339, Université de Bordeaux I, Avenue des Facultés, 33405 Talence Cedex, *France*

A. Jeeva, Department of Psychology, University of Calgary, 2500 University Drive N.W., Calgary, Alberta T2N 1N4, *Canada*

Lu Jun, Department of Biology, Texas A&M University, College Station, TX 77843, *USA*

Teresa A. Kelm, Department of Biology, Texas A&M University, College Station, TX 77843, *USA*

Anthony R. McIntosh, Department of Psychology and Institute for Neuroscience, University of Texas, Austin, TX 78712, *USA*

C. Messier, School of Psychology, University of Ottawa, 145 Jean-Jacques Lussier, Ottawa, Ontario K1N 6N5, *Canada*

José N. Nobrega, Neuroimaging Research Section, Clarke Institute of Psychiatry, 250 College Street, Toronto, Ontario M5T 1R8, *Canada*

F. Ohl, Institute for Zoology, Technical University Darmstadt, Schnittspahnstr. 3, D-6100 Darmstadt, *Germany*

Carlo A. Porro, Institute of Human Physiology and Neurology, University of Modena, Via Campi 287, 41100 Modena, *Italy*

Hinrich Rahmann, Institute of Zoology, University of Stuttgart-Hohenheim, Garbenstr. 30, 7000 Stuttgart 70, *Germany*

Peter Room, Department of Anatomy and Embryology, University of Groningen, Oostersingel 69, 9713 EZ Groningen, *The Netherlands*

G. S. F. Ruigt, Department of CNS-Pharmacology, Organon International B.V., 5340 BH Oss, *The Netherlands*

Stephen M. Sagar, Department of Neurology, University of California at San Francisco, Veterans Administration Medical Center, 4150 Clement Street, San Francisco, CA 94121, *USA*

Henning Scheich, Institute for Zoology, Technical University Darmstadt, Schnittpahnstr. 3, D-6100 Darmstadt, *Germany*

Frank R. Sharp, Department of Neurology, University of California at San Francisco, Veterans Administration Medical Center, 4150 Clement Street, San Francisco, CA 94121, *USA*

J. Sif, Département de Biologie, Université d'El Jadida, BP 20, El Jadida, *Morocco*

C. Simonis, Institute for Zoology, Technical University Darmstadt, Schnittpahnstr. 3, D-6100 Darmstadt, *Germany*

L. Sokoloff, National Institute of Mental Health, Laboratory of Cerebral Metabolism, Building 36 Room 1A-05, Bethesda, MD 20892, *USA*

Timothy T. Soncrant, Laboratory of Neurosciences, National Institute of Aging, National Institutes of Health, Bldg. 10 Rm. 6C414, Bethesda, MD 20892, *USA*

H. Thomas, Institute for Zoology, Technical University Darmstadt, Schnittpahnstr. 3, D-6100 Darmstadt, *Germany*

G. A. Thurlow, Department of Psychology, University of Calgary, 2500 University Drive N.W., Calgary, Alberta T2N 1N4, *Canada*

J. Tillein, Institute for Zoology, Technical University Darmstadt, Schnittpahnstr. 3, D-6100 Darmstadt, *Germany*

Wade S. Warren, Department of Biology, Texas A&M University, College Station, TX 77843, *USA*

A. D. Weissman, Addictions Research Center, Department of Neuroscience, NIDA,
Baltimore, MD 21224, *USA*

E. Zimmermann, Deutsches Primatenzentrum GmbH, Kellnerweg 4, 3400 Göttingen,
Germany