The Oscillatory Nature of Language

Drawing on cutting-edge ideas from the biological and cognitive sciences, this book presents both an innovative neuro-computational model of language comprehension and a state-of-the-art review of current topics in neurolinguistics. It explores a range of newly emerging topics in the biological study of language, building them into a framework which views language as grounded in endogenous neural oscillatory behaviour. This allows the author to formulate a number of hypotheses concerning the relationship between neurobiology and linguistic computation. Murphy also provides an extensive overview of recent theoretical and experimental work on the neurobiological basis of language, from which the reader will emerge up to date on major themes and debates. This lively overview of contemporary issues in theoretical linguistics, combined with a clear theory of how language is processed, is essential reading for scholars and students across a range of disciplines.

ELLIOT MURPHY is a research associate at the Vivian L. Smith Department of Neurosurgery, McGovern Medical School, University of Texas Health Science Center, at the Texas Institute for Restorative Neurotechnologies. He has published widely on the neurobiology of syntax, language evolution, and current topics in semantics, pragmatics and philosophy.

The Oscillatory Nature of Language

Elliot Murphy

McGovern Medical School, University of Texas Health Science Center

CAMBRIDGE
UNIVERSITY PRESS

CAMBRIDGE
UNIVERSITY PRESS

University Printing House, Cambridge CB2 8BS, United Kingdom

One Liberty Plaza, 20th Floor, New York, NY 10006, USA

477 Williamstown Road, Port Melbourne, VIC 3207, Australia

314–321, 3rd Floor, Plot 3, Splendor Forum, Jasola District Centre,
New Delhi – 110025, India

79 Anson Road, #06–04/06, Singapore 079906

Cambridge University Press is part of the University of Cambridge.

It furthers the University's mission by disseminating knowledge in the pursuit of education, learning, and research at the highest international levels of excellence.

www.cambridge.org
Information on this title: www.cambridge.org/9781108836319
DOI: 10.1017/9781108864466

First published 2021

A catalogue record for this publication is available from the British Library.

Library of Congress Cataloging-in-Publication Data
Names: Murphy, Elliot, author.
Title: The oscillatory nature of language / Elliot Murphy, University College London.
Description: Cambridge, UK ; New York : Cambridge University Press, 2020. | Includes bibliographical references and index.
Identifiers: LCCN 2020026174 (print) | LCCN 2020026175 (ebook) | ISBN 9781108836319 (hardback) | ISBN 9781108864466 (ebook)
Subjects: LCSH: Biolinguistics. | Neurolinguistics. | Psycholinguistics. | Neuropsychology. | Cognitive neuroscience.
Classification: LCC QP360 (print) | LCC QP360 (ebook) | DDC 612.8–dc23
LC record available at https://lccn.loc.gov/2020026174
LC ebook record available at https://lccn.loc.gov/2020026175

ISBN 978-1-108-83631-9 Hardback

'Yes, a key can lie forever in the place where the locksmith left it, and never be used to open the lock the master forged it for.'

– Ludwig Wittgenstein, *Culture and Value* (1977, 54)

'I fear those big words, Stephen said, which make us so unhappy.'

– James Joyce, *Ulysses* (1998, 31)

Contents

Preface *page* xi

Introduction 1

1 Theory and Praxis 16
1.1 Language Architecture 19
1.2 The 'Mechanical Power' of Language 20
1.3 Language Evolution: Conflicting Models 22
1.4 Past, Present and Emerging Terrain 26
1.5 Simplicity and Neural Organisation 32
1.6 A System of Discrete Infinity 37
1.6.1 Concatenation 38
1.6.2 Agree 39
1.6.3 Natural Numbers 39
1.6.4 Adjuncts 40
1.6.5 Labelling 41
1.7 Animal Syntax 42
1.7.1 Formal Languages 42
1.7.2 Hierarchy 46
1.7.3 Compositionality 47
1.8 Mapping Syntax and Sentence Processing 48
1.9 Homo Projectans 51

2 Brain Dynamics of Language 53
2.1 Theoretical Overview 54
2.1.1 Anatomy 54
2.1.2 Granularity 56
2.1.3 Cartographic Directions 59
2.1.4 Evo-Devo Directions 62
2.2 Oscillations as Functional Units 64
2.2.1 Neural Syntax 66
2.2.2 Theory vs. Data Redescription in the Study of Language 81
2.3 Applications and Consequences 92
2.3.1 Autism and Schizophrenia: The 'Price' We Paid for Language 92
2.3.2 Prediction and Binding 92
2.3.3 Empirical Consequences 96
2.3.4 Feeble Currents 98

2.3.5 Cross-Frequency Coupling 102
2.3.6 Free Energy and the Hidden States of the World 104
2.3.7 Communication-through-Coherence 107
2.3.8 Operations and their Constraints: Merge, Anti-identity and *{t,t} 110
2.4 Globularity and Cortico-centrism 113
2.4.1 Striatal Disorders 118
2.4.2 Thalamic and Temporal Combinatorics 118
2.5 Learn to Code: Implementing Hierarchical Phrase Structure 123
2.5.1 Reconstructing Language 126
2.5.2 Functional Polyhedra: Localisation of Linguistic Function 131

3 A Neural Code for Language 135
3.1 Encoding Feature-Sets 137
3.1.1 Refining the θ-γ Code 137
3.1.2 Hub, Spoke and Causation 143
3.2 Encoding Phrasal Units 147
3.2.1 What We Talk About When We Talk About δ 147
3.2.2 The Evolution of Language 156
3.2.3 Phase–Phase Coupling and Other Approaches to Neural Computation 159
3.2.4 Linear Grammar 163
3.3 A Bridge to Biology 164
3.3.1 Dual Workspaces 164
3.3.2 γ-Itemisation 169
3.4 Refining the Model 174
3.4.1 Frequency Generators 174
3.4.2 Basic Arithmetic 175
3.4.3 Coupling Concerns 176
3.4.4 Plasticity 178
3.4.5 Ironic α Decreases 179
3.5 Further Topics in Memory, Attention and Combinatoriality 183
3.5.1 Hippocampal Binding 183
3.5.2 Cartographic Reconciliation 184
3.5.3 Grounding Memory and Attention 187
3.5.4 Reservoir Computing, Discrete Results and the Syntax of Silence 193
3.5.5 Modelling Phrase Structure Generation via Phase–Amplitude Coupling 195
3.6 Implications and Qualifications 199
3.6.1 Language Acquisition and its Implications for the Oscillome 199
3.6.2 Processes and Processors 201
3.6.3 The Physics of Language: Finding a ‘Perfect’ Solution 206
3.6.4 The Representation Problem 208
3.6.5 Philosophical Reflections 213
3.7 Extending the Model 217
3.7.1 Travelling Oscillations 217
3.7.2 Neuroethological Perspectives on the Neural Code for Language 226

4 Conclusions and Future Directions 234

Glossary 246
References 249
Index 319

Preface

This book is the culmination of a five-year effort to develop a series of linking hypotheses between components of the language faculty – principally, its computational basis – and components of neurobiology, namely oscillatory behaviour. First conceived in November 2014, I began researching ways to approach a monographic treatment of this topic. In order to achieve this, it would first be necessary to discover a feasible means to decompose 'narrow syntax' considerably further than it has typically been in the literature. For instance, the generative grammar literature mostly takes Merge to be an elementary operation rather than a complex of, at least, *search*, *combine*, *categorise* and *maintain*. Next, one would need to identify neural mechanisms (and not purely regions) putatively capable of carrying out these operations. This gradually developed into an effort to go beyond what soon became the field's go-to neural mechanism for phrasal comprehension, oscillatory 'entrainment' – what is regarded in this book as only the first step in a complex network-level process of endogenous cross-frequency couplings (based on ideas proposed in Murphy 2015b, 2016a).

Soon after, my aim became to distinguish between theoretical formulations in the neurolinguistics literature that don't really carry much explanatory weight (and are used to re-describe the output of statistical analyses performed on neuroimaging datasets, rather than account for them) and forms of theoretical formulations that really don't carry much explanatory weight. A general trend has emerged whereby – to take a common example – amplitude increases in a particular, canonical frequency band are coded as underlying complex cognitive processes, and yet there are no neurobiologically realistic computational roles being ascribed to such frequencies. Or, when we reach a moment when even the decidedly specific process of δ-β phase–amplitude coupling is being associated with both motor control inhibition during the processing of task-relevant abstractions and the effects of paternal (but not maternal) caregiving behaviours on the brains of preschool children, it seems clear that a momentary departure from data collection is required. Successful model formulation is not achieved by constructing new labels for well-established abstractions, as when Hagoort (2019, 55) proposes a re-naming of *operations* to 'elementary linguistic operations (ELOs)' and a re-naming of *representations* to 'elementary linguistics units (ELUs)', a move which brings with it no new insights into the nature of operations and representations.

Although certain studies have begun to show that particular linguistic operations are indexed by specific neural behaviour in certain cortical regions, what is currently lacking in the field is a comprehensive explanatory account for why we find the neural signatures that we do. For instance, why do γ oscillations appear to index successful semantic composition? Pointing to the fact that γ typically indicates local cortical processing is not sufficient, since the gap in abstraction level between semantic processing and high-frequency action potential firing is not something that will be bridged automatically or seamlessly.

As I began developing preliminary versions of an empirically and theoretically defensible oscillatory model of phrase structure building throughout 2014–2019, similar spectres emerged: an unjustified cortico-centric emphasis in standard neurolinguistic models, sidelining the crucial role of subcortical structures in language; an inability for standard models to account for neuroplasticity; a neurobiologically unrealistic insistence that a specific subregion of Broca's area is the 'seat of syntax'; and a hidebound focus on localisation of function (as when, in his Foreword to Friederici's recent monograph, Chomsky claims that 'it is the ventral part of B44 [sic] in which basic syntactic computations – in the simplest case Merge – are localized'; Friederici 2017, x), as opposed to the construction of a more dynamic neural code for language, potentially realisable across multiple neural systems.

Early on in this process, a more fundamental goal had been achieved: isolating the components of language suitable for potential neurobiological grounding. Having reviewed existing ethological research into non-human cognitive capacities, I isolated primarily the *labelling* component in natural language as being of sufficient granularity (being a form of categorisation and object maintenance) to map onto postulated computational properties of certain oscillatory processes. Other components, such as representational storage in a derivational workspace and intrinsic representational complexity, were proposed as candidates for neural mapping. In brief, the goal has been to accommodate language-specific components postulated by theoretical syntax within a particular framework of neural computation.

By 2020, it became increasingly clear across a number of fields in the neurobiology of cognition that cellular and oscillatory mechanisms, once believed to be highly domain-specific, are in fact recruited in the service of computationally analogous processes operating over distinct representational domains. This book has attempted to apply this insight to language, pushing this approach as strongly for the 'broad' faculty of language (e.g. the sensorimotor system, representational storage) as it does for the 'narrow' faculty (phrase structure building via labelling).

It is my sincere hope that by turning away from rhetorical re-formulations and towards theoretical neurobiology, and synthesising the wealth of currently available empirical findings concerning the oscillatory nature of language, this book can encourage others to pursue the paramount task of model formulation, and thereby ground the computational nature of language within intrinsic neural processes.