Linguistic Morphology in the Mind and Brain

Edited by Davide Crepaldi

Current Issues in the Psychology of Language

"This volume is an essential new reference for psycholinguistic approaches to morphology. It presents a comprehensive and up-to-date overview of the most important findings and theories in the domain, and will appeal to both experts and newcomers within the field. The topics chosen invite the reader to consider morphology from a range of perspectives, and thus to appreciate the profound relationship between linguistic structure, acquisition, and processing."

– **Professor Kathy Rastle**, *Royal Holloway, University of London, UK*

"The study of word processing provides a fantastic window on the human mind. This volume provides an excellent and authorative guide to the state-of-the-art in present-day research on how words are processed, from all relevant perspectives: production and perception, speech and writing, and the acquisition of these abilities. This book is therefore an indispensable guide for students and researchers in this domain of psycholinguistic research."

– **Geert Booij**, *Emeritus Professor of Linguistics, Leiden University, Netherlands*

Taylor & Francis
Taylor & Francis Group
http://taylorandfrancis.com

LINGUISTIC MORPHOLOGY IN THE MIND AND BRAIN

Linguistic Morphology is a unique collection of cutting-edge research in the psycholinguistics of morphology, offering a comprehensive overview of this interdisciplinary field.

This book brings together world-leading experts from linguistics, experimental psychology, and cognitive neuroscience to examine morphology research from different disciplines. It provides an overview of how the brain deals with complex words, examining how they are easier to read, how they affect our brain dynamics and eye movements, how they mould the acquisition of language and literacy, and how they inform computational models of the linguistic brain. Chapters discuss topics ranging from subconscious visual identification to the high-level processing of sentences, how children make their first steps with complex words through to how proficient adults make lexical identification in less than 40 milliseconds.

As a state-of-the-art resource in morphology research, this book will be highly relevant reading for students and researchers of linguistics, psychology, and cognitive neuroscience. It will also act as a one-stop shop for experts in the field.

Davide Crepaldi is an Associate Professor at SISSA, Trieste, Italy, and also Associate Editor at the British Journal of Psychology and at Psychonomic Bulletin and Review. He received his PhD in Cognitive Neuroscience at the University of Milano-Bicocca, Italy.

CURRENT ISSUES IN THE PSYCHOLOGY OF LANGUAGE

Series Editor: Trevor A. Harley

Current Issues in the Psychology of Language is a series of edited books that will reflect the state-of-the-art in areas of current and emerging interest in the psychological study of language.

Each volume is tightly focused on a particular topic and consists of seven to ten chapters contributed by international experts. The editors of individual volumes are leading figures in their areas and provide an introductory overview.

Example topics include: language development, bilingualism and second language acquisition, word recognition, word meaning, text processing, the neuroscience of language, and language production, as well as the inter-relations between these topics.

Sentence Processing
Edited by Roger van Gompel

Speech Perception and Spoken Word Recognition
Edited by M. Gareth Gaskell and Jelena Mirković

Visual Word Recognition Volume 1
Edited by James S. Adelman

Visual Word Recognition Volume 2
Edited by James S. Adelman

Linguistic Morphology
Edited by Davide Crepaldi

Language Production
Edited by Robert J. Hartsuiker and Kristof Strijkers

LINGUISTIC MORPHOLOGY IN THE MIND AND BRAIN

Edited by Davide Crepaldi

Routledge
Taylor & Francis Group
LONDON AND NEW YORK

Cover image: © matdesign24/Getty Images

First published 2023
by Routledge
4 Park Square, Milton Park, Abingdon, Oxon OX14 4RN

and by Routledge
605 Third Avenue, New York, NY 10158

Routledge is an imprint of the Taylor & Francis Group, an informa business

British Library Cataloguing-in-Publication Data
A catalogue record for this book is available from the British Library.

Library of Congress Cataloging-in-Publication Data
A catalog record has been requested for this book.

ISBN: 978-0-367-74828-9 (hbk)
ISBN: 978-0-367-67958-3 (pbk)
ISBN: 978-1-003-15975-9 (ebk)

DOI: 10.4324/9781003159759

Typeset in Bembo
by Taylor & Francis Books

CONTENTS

ILLUSTRATIONS

Figures

Tables

LIST OF CONTRIBUTORS

Mark Aronoff
Department of Linguistics
Stony Brook University
United States

R. Harald Baayen
Department of Linguistics
Eberhard Karls Universität, Tübingen
Germany

Raymond Bertram
Department of Psychology and Speech-Language Pathology
University of Turku
Finland

Elisabeth Beyersmann
School of Psychological Sciences and Macquarie University Centre for Reading
Macquarie University, Sydney
Australia

Sendy Caffarra
Department of Biomedical Sciences
University of Modena and Reggio Emilia
Italy

and

Division of Developmental and Behavioral Pediatrics
Stanford University
United States

Yu-Ying Chuang
Department of Linguistics
Eberhard Karls Universität, Tübingen
Germany

Ava Creemers
Department of Psychology of Language
Max Planck Institute for Psycholinguistics, Nijmegen
The Netherlands

Ben Davies
Department of Linguistics
Macquarie University, Sydney
Australia

Katherine Demuth
Department of Linguistics
Macquarie University, Sydney
Australia

Christina Gagné
Department of Psychology
University of Alberta, Edmonton
Canada

Jonathan Grainger
Cognitive Psychology Laboratory
CNRS and University of Aix-Marseille
France

Laura Gwilliams
Department of Neurological Surgery,
University of California, San Francisco
United States

Jana Hasenäcker
Department of Linguistics
University of Erfurt
Germany

Jukka Hyönä
Department of Psychology and Speech-Language Pathology
University of Turku
Finland

Mihi Kang
Department of Linguistics
Eberhard Karls Universität, Tübingen
Germany

Xuefeng Luo
Junior Cloud, Stuttgart
Germany

Alec Marantz
Department of Linguistics and Department of Psychology
New York University
United States

Marco Marelli
Department of Psychology
University of Milano-Bicocca
Italy

Petroula Mousikou
Spinger Nature, Berlin
Germany

and

Institute of Psychology
University of Goettingen
Germany

Sascha Schroeder
Institute of Psychology
University of Goettingen
Germany

Andrea Sims
Department of Linguistics
Ohio State University
United States

Thomas S. Spalding
Department of Psychology
University of Alberta, Edmonton
Canada

Marcus Taft
Centre for Cognitive Science of Language
Beijing Language and Culture University
China

and

School of Psychology
University of New South Wales, Sydney
Australia

Alexander Taikh
Department of Psychology
Concordia University of Edmonton
Canada

Fabian Tomaschek
Department of Linguistics
Eberhard Karls Universität, Tübingen
Germany

Benjamin V. Tucker
Department of Linguistics
University of Alberta, Edmonton
Canada

and

Department of Communication Sciences & Disorders
Northern Arizona University
United States

1

INTRODUCTION

An Interdisciplinary View on the Future of the Field

Davide Crepaldi

When I was first approached about the possibility of editing this book, I hesitated. I considered that it is always very difficult to provide an overview of a field of research; this is, ultimately, a human community, and as such, it has a life of its own – with complex dynamics, pressures that lead the research in different directions, nicely converging findings and views, along with long-standing controversies and inconsistent data that still wait for a convincing account. Even if I could claim to know all the relevant findings and theories (another impossible task in these times of strong scientific productivity), it would be impossible to do justice to the diversity of ideas, approaches and points of view that characterise the study of complex word processing.

What makes this book so difficult to compose, however, is also what makes it useful. Even in a small field like linguistic morphology, as an expert in the visual identification of single words, I've been wondering so many times in my career whether my findings had a parallel in, for example, spoken word production, or what theoretical linguists would think of my theorising, or what the hot topics were in, for example, sentence processing or language acquisition. Another common situation in which I wished I had a book like this was when a new student would come up and declare their interest in morphological processing. Of course, I could easily point them to a few key papers in the psycholinguistics of visual word identification, but I wouldn't know how to offer them a comprehensive overview that would go above my narrow field and community. So, in the end, I just made peace with the idea that I was bound to fail, and accepted the invitation of the Series Editor, Gareth Gaskell, whom I wish to thank for thinking of me for this endeavour.

The first thing I figured was that my only hope to fail a bit less miserably was to abandon the ambition of being truly exhaustive, and just rely on the hive mind. So, instead of trying to come up myself with what constitutes fundamental

DOI: 10.4324/9781003159759-1

knowledge for the morphology psycholinguist, I invited leading scholars in different fields (e.g. spoken word identification, speech production, reading acquisition, eye movements) to tell the reader how their own community is keeping itself busy. This book will have surely left out some relevant research, for which I offer my apologies; but I hope I will have succeeded in providing the reader with a nice snapshot of the discipline as it exists today.

One nice feature of this snapshot is that it is highly interdisciplinary. The book's primary target is surely the psycholinguistic field, but I really tried to offer an integrated view that includes at least linguistics, cognitive neuroscience, and developmental psychology. I encouraged every chapter author to write in a style that would be accessible to specialists in other fields, and to adopt the perspective of someone who would like their own terminology, objects of study, concepts – ideas, ultimately – to be used outside of their own discipline. Some parts are inevitably more technical than others, but overall I am confident that any morphology scholar should be able to understand any part of this book and see a connection with their own current work. This interdisciplinary reach has its costs, of course; for example, I suspect that some terminology might mean different things in different disciplines (see the usage of the term 'lexeme' in Chapter 2 and 'lemma' in Chapter 10). However, the chapter authors and I preferred to remain faithful to the current debate in each discipline, clearing up any possible confusion via explicit definitions rather than compromising on terminologies that are very established within their own respective academic communities.

Contributors from different fields tend to offer different interpretations of the same phenomena. A nice example is the classic corner-corn effect; in (visual) masked priming, pseudo-derived words such as *corner* tend to facilitate the processing of their pseudo-stems (*corn*) more than orthographic controls without an apparent morphological structure (e.g. *dialog-dial*) and, in most reports, not so differently from genuine derivations (e.g. *dealer-deal*; e.g. Longtin et al., 2003; Rastle et al., 2004). This has been mostly interpreted as a visual-orthographic phenomenon in the field of visual word identification (e.g. Crepaldi et al., 2010; Grainger & Beyersmann, 2017; Grainger & Ziegler, 2011; Lelonkiewicz et al., 2020; Rastle, 2003). Linguists tend to have a different reading of the phenomenon; in Chapter 10 in this book, Laura Gwilliams and Alec Marantz take it to indicate a mapping between a stored representation that is abstract in nature (i.e. not particularly tight to any combination of phonemes or graphemes) and the actual input. (There is emphasis on the abstract vs. specific nature of morphological representations in other chapters, too, like in Chapter 4 by Ava Creemers, Chapter 5 by Marco Marelli, and Chapter 6 by Benjamin V. Tucker and Fabian Tomaschek.) Of course, these different interpretations have strengths and weaknesses; more precisely, they probably reflect different perspectives on the matter – more focussed on the specific processes that a computational machine might put in place for the psycholinguists, more attentive to preserving the genuine nature of the concept of morphology for the linguists. I love that the book came up representing these differences, and I encourage the reader, particularly the student approaching the discipline for the first time, to appreciate this diversity and build an original point of view, rather than choose a camp.

The representation of diversity doesn't end with a contrast between the approach taken by different academic communities. The book also offers a snapshot of the current state of the debate within individual disciplines. The reader will find many examples in the book; I'll only mention two here, which illustrates another interesting point for what concerns the naturally interdisciplinary arena that morphology offers. Mark Aronoff and Andrea Sims describe several theories that have been proposed in theoretical linguistics to account for the morphological domain. Gwilliams and Marantz add to this picture with their own focus on one of these approaches, Distributed Morphology, and the way this approach has guided them in the exploration of the brain. In the cognitive psychology domain, you will see a nice tension between theories that posit the existence of morphological representations (Chapter 3, by Lisi Beyersmann and Jonathan Grainger, and Chapter 11, by Marcus Taft) and models that dispose of them (Chapter 12, by Yu-Ying Chuang, Mihi Kang, Xuefeng Luo, and Harald Baayen). Interestingly, the debate seems to revolve around the same issue in the two disciplines – whether we need an explicit level of morphological representations. It is not obvious, however, that the term "representation" means the same thing in theoretical linguistics and psychology. In fact, I suspect that it's not very clear what we mean by representations in general – or at the very least, that we mean the same thing when we debate about their necessity. At some level of description, all theoretical models are metaphors; they don't necessarily refer to physical entities, like neural ensembles, or informational machines, like a set of operations that change the features of those neural ensembles. We can be happy with models that offer a nice metaphorical account for experimental facts and, most importantly, generate testable predictions (e.g. Coltheart et al., 2001). But clearly, some scholars believe models provide more than that, as they search for representations in the brain (see, again, the literature reviewed by Laura Gwilliams and Alec Marantz in Chapter 10). In Harald Baayen's approach, the lack of explicit morphological representations comes from a fundamental learning algorithm that is not specific for language; so, the message becomes even wider, and more ambitious, suggesting that one doesn't need language-specific cognitive machinery to account for morphological effects (e.g. Baayen et al., 2011).

I think that this kind of modelling issues really represent the frontiers of the field at the moment; we psycholinguists are generally more focused on running experiments and gathering data, but it seems to me that we have a solid enough data basis now to try and scale up our modelling effort. Some critical questions are waiting for us on that front: does the system ever reach an end-state, or are we rather continuously learning and updating our morphological processing system? If the latter, does this change substantially the machinery in the mind and brain of the adult, fully proficient speaker/reader, or it's rather minor adjustments? When we become fully accustomed with a morphological system, do we continue to use the distributed, associative machine (e.g. NDL) that has enabled the learning in the first place, or do we rather settle on a different "mode", where some other kind of representations –which have perhaps indeed emerged from that machine– are used instead? I find this latter question particularly interesting, since it connects with the more general issue we raised in the previous paragraph: how much do we believe that our models are actual descriptions of the workings of the ultimate computational tools that we must use, that is, individual neurons?

I would like to stress a couple of final points before leaving the reader with the more interesting chapters. In Chapter 14, Jana Hasenäcker, Petroula Mousikou and Sascha Schroeder talk at length about morphological awareness, a meta-linguistic task that is very popular in the literature connecting morphological processing and reading development. This raises an interesting question about whether this kind of meta-linguistic skills are based on similar cognitive mechanisms as the largely implicit phenomena that are described in the rest of the book (e.g., priming; e.g., Grainger et al., 1991; morpheme frequency effects, e.g., Burani et al., 1984; Juhasz et al., 2003; Taft, 1979; sensitivity to the entropy of morphological families; e.g., Moscoso del Prado Martin et al., 2004). The little evidence we have in this respect is mostly incidental (e.g., De Rosa & Crepaldi, 2021), but this is clearly a critical issue if we want to provide a comprehensive account of morphological processing: do explicit and implicit morphological skills rely on the same cognitive processes? Do they correlate, even? This question connects with another issue that perhaps doesn't particularly shine in this book, but it is starting to emerge in the morphological field, as well as in psycholinguistics more generally: individual differences (e.g., Andrews & Lo, 2013; Beyersmann et al., 2015; Milin et al., 2017; Viviani & Crepaldi, 2022). For years, we've been fighting individual differences; these latter were essentially noise that obscured group-level effects, which were the real target of our investigation. This perspective is starting to change now; individual differences are part of the psychological phenomena that we're interested in and constitute a target of our work, both experimentally and in terms of modelling. A very instrumental role in this renewed interest in individual differences was played by the fantastic Sally Andrews, whose great contribution to the field – in terms of both science and leadership – I want to acknowledge.

Another interesting point comes up very clearly in Chapter 4, where Ava Creemers explains how the physical properties of the medium that carries the information might critically affect the way cognition works. In this specific case, the comparison was between listening (spoken language) and reading (written language), which unfolds over time and space, respectively, which in turns calls for very different assumptions on how the brain might optimally capture information. I suspect that this same issue might apply more generally; think of the comparison between printed and handwritten text, as nicely illustrated in Chapter 7 by Christina Gagné, Thomas Spalding and Alexander Taikh and between morphological processing with and without context, as pointed out by Raymond Bertram and Jukka Hyönä. We should probably give more thought to how language is differentially conveyed in different modalities and under different circumstances, and how this might affect morphological processing. Perhaps, we should even start modelling these differences more explicitly, now that our theories on the underlying abstract representations are more mature.

In closing, a final call to try and overcome the boundaries of the narrow field. The internal structure of words is an extremely interesting issue (of course). It is also an invaluable window into how the human mind reaches a balance between storage and computation. On the one hand, we need many labels to be able to express our thoughts; but on the other hand, our memory is limited. Morphology gives regularity to the mapping between form and meaning, in a way that with a lesser number of elements (the morphemes), we obtain a nicely compact, and yet powerful system (e.g., Kirby et al., 2008; Monaghan et al., 2011). This perspective highlights the strict, perhaps fundamental connection between morphology, orthography and meaning (and potentially, syntax, too); surely, these are legitimately different levels of linguistic description, but they need not be separated levels of processing in the mind and the brain. As morphologists, we should never forget this, and perhaps move our field towards an even stronger integration with other disciplines and communities, with the aim of producing a more integrated basis of experimental evidence and, hopefully, more integrated models of linguistic cognition.

References

Andrews, S., & Lo, S. (2013). Is morphological priming stronger for transparent than opaque words? It depends on individual differences in spelling and vocabulary. *Journal of Memory and Language* 68 (3), 279–296. doi:10.1016/j.jml.2012.12.001.

Baayen, R. H., Milin, P., Durdevic, D. F., Hendrix, P. & Marelli, M. (2011). An amorphous model for morphological processing in visual comprehension based on naive discriminative learning. *Psychological Review*, 118 (3), 438–481. doi:10.1037/a0023851.

Beyersmann, E., Casalis, S., Ziegler, J. C. & Grainger, J. (2015). Language proficiency and morpho-orthographic segmentation. *Psychonomic Bulletin & Review*, 22, 1054–1061. doi:10.3758/s13423-014-0752-9.

Burani, C., Salmaso, D. & Caramazza, A. (1984). Morphological structure and lexical access. *Visible Language*, 18 (4), 342–352. http://visiblelanguage.s3.amazonaws.com/pdf/18.4/morphological-structures-and-lexical-access.pdf.

Coltheart, M., Rastle, K., Perry, C., Langdon, R. & Ziegler, J. (2001). DRC: A Dual Route Cascaded model of visual word recognition and reading aloud. *Psychological Review*, 108 (1), 204–256. doi:10.1037/0033-295x.108.1.204.

Crepaldi, D., Rastle, K., Coltheart, M. & Nickels, L. (2010). 'Fell' primes 'fall', but does 'bell' primes 'ball'? Masked priming with irregularly-inflected primes. *Journal of Memory and Language*, 63 (1), 83–99. doi:10.1016/j.jml.2010.03.002.

De Rosa, M., & Crepaldi, D. (2021). Letter chunk frequency does not explain morphological masked priming. Psychonomic Bulletin and Review, 29, 589–599. doi:10.3758/s13423-021-02010-y.

Grainger, J., & Beyersmann, E. (2017). Edge-aligned embedded word activation initiates morpho-orthographic segmentation. *Psychology of Learning and Motivation*, 67, 285–317. doi:10.1016/bs.plm.2017.03.009.

Grainger, J., Colé, P. & Segui, J. (1991). Masked morphological priming in visual word recognition. *Journal of Memory and Language*, 30 (3), 370–384. doi:10.1016/0749-596X(91)90042-I.

Grainger, J., & Ziegler, J. C. (2011). A dual-route approach to orthographic processing. *Frontiers in Language Sciences*, 2, 54. doi:10.3389/fpsyg.2011.00054/full.

Juhasz, B. J., Starr, M. S., Inhoff, A. W. & Placke, L. (2003). The effects of morphology on the processing of compound words: evidence from naming, lexical decisions and eye fixations. *British Journal of Psychology*, 94, 223–244. doi:10.1348/000712603321661903.

Kirby, S., Cornish, H. & Smith, K. (2008). Cumulative cultural evolution in the laboratory: an experimental approach to the origins of structure in human language. *Proceedings of the National Academy of Sciences of the US*, 105 (31), 10681–10686. doi:10.1073/pnas.0707835105.

Lelonkiewicz, J. R., Ktori, M. & Crepaldi, D. (2020). Morphemes as letter chunks: discovering affixes through visual regularities. *Journal of Memory and Language*, 115, 104152. doi:10.1016/j.jml.2020.104152.

Longtin, C.-M., Segui, J. & Hallé, P. A. (2003). Morphological priming without morphological relationship. *Language and Cognitive Processes*, 18 (3), 313–334. doi:10.1080/01690960244000036.

Milin, P., Feldman, L. B., Ramscar, M., Hendrix, P. & Baayen, H. (2017). Discrimination in lexical decision. *PLoS ONE*, 12, e0171935. doi:10.1371/journal.pone.0171935.

Monaghan, P., Christiansen, M. H. & Fitneva, S. A. (2011). The arbitrariness of the sign: learning advantages from the structure of the vocabulary. *Journal of Experimental Psychology: General*, 140 (3), 325–347. doi:10.1037/a0022924.

Moscoso del Prado Martín, F., Kostic, A. & Baayen, R. H. (2004). Putting the bits together: an information theoretical perspective on morphological processing. *Cognition* 94 (1), 1–18. doi:10.1016/j.cognition.2003.10.015.

Rastle, K., Davis, M. H. & New, B. (2004). The broth in my brother's brothel: Morpho-orthographic segmentation in visual word recognition. *Psychonomic Bulletin & Review*, 11 (6), 1090–1098. doi:10.3758/bf03196742.

Taft, M. (1979). Recognition of affixed words and the word frequency effect. *Memory and Cognition*, 7, 263–272. doi:10.3758/BF03197599.

Viviani, E., & Crepaldi, D. (2022). Masked morphological priming and sensitivity to the statistical structure of form-to-meaning mapping in L2. *Journal of Cognition*, 5 (1), 30. doi:10.5334/joc.221/.

2

THE RELATIONAL NATURE OF MORPHOLOGY[1]

Mark Aronoff and Andrea D. Sims

Introduction and brief history

The term *morphology* was coined by Goethe and soon spread to several nascent sciences, from biology to geology, as a term for the study of form or forms. August Schleicher, the premier linguist of his time, introduced it to linguistics in the 1850s. He used it to refer to the study of the forms of complex words. Compare a morphologically simple word like the English adjective *slow* to its complex adverbial counterpart *slowly*. The latter contains an additional element, the suffix *-ly*. Intuitively, we might say that the adverb is formed by the addition of the suffix to the adjective. Linguists and psychologists have spent the last 150 years fleshing out this intuition.

Languages differ greatly in their morphological complexity. At one end, we have a language like Vietnamese, which has no affixes to speak of. The only means its speakers have to form complex words is by putting two otherwise independent words together, along the lines of German *Handschuh* 'glove' (lit. 'handshoe') or French *lave vaisselle* 'dishwasher'. At the other extreme lies Kalaallisut (kala1399),[2] the official language of Greenland, where the single word *Aliikkusersuillammassuaanerartassagaluarpaalli* contains a dozen discernible pieces and can be translated roughly as 'However, they will say that he is a great entertainer, but'. Most European languages lie somewhere in between. They range from English and the Scandinavian languages, with fairly simple morphology, through German and the Romance languages with gender agreement and more complex noun or verb inflection, to Finnish and Euskara (Basque, basq1248), where the suffixes can pile up quite quickly.

To this day, many linguists share the basic assumption that complex words are built out of atomic meaningful elements called *morphemes*. Structuralist linguists thought of morphology in terms of morphemes and how they are put together to

DOI: 10.4324/9781003159759-2

make words and sentences (e.g. Harris 1942; Hockett 1947), and this is how morphology still tends to be taught at an introductory level. Jan Baudouin de Courtenay, who coined the term in the late 19th century, framed his definition in explicitly psychological terms: 'that part of a word which is endowed with psychological autonomy and is for the very same reason not further divisible' (Baudouin de Courtenay 1972: 153). This goal of breaking words down into parts that are 'not further divisible' is clearly aligned with 19th-century science. This scientising desire has remained with the field ever since.

Morphology is conventionally divided into *inflection*, which deals with the forms that a single word (or *lexeme* in linguists' terminology) takes, and *derivation* or *word formation*, whose realm is the relation between lexemes. The inflected *word forms* of the verb lexeme TASTE are *taste, tastes, tasting* and *tasted*. From this verb, we may form the noun *taster* and the adjectives *tasteful, tasteless* and *tasty*. From these, in turn, we may form *tastefully, tastelessness* and *tastily*. The relation between the semantically related homophonous verb and noun *taste* is not clear, and both have many senses. As in many fields, there is a constant battle between what Darwin called 'lumpers' and 'splitters' over whether each of these senses comprises a separate word in some sense. The relations among the members of such word families have also become fertile ground for experimental study.

The study of morphology, though central to Structuralist approaches to linguistics in the first half of the 20th century (e.g. Nida 1949), was not central to the early Generative programme (Chomsky 1957). Chomsky (1965)'s Aspects of the Theory of Syntax, one section of which bears the title '*The Structure of the Lexicon*', discusses morphology only briefly. Early Generative Grammar generally divided the territory of morphology between syntax and phonology. Modern Generative frameworks such as Distributed Morphology (see Siddiqi 2019 for an overview) and Nanosyntax (see Baunaz and Lander 2018) continue key aspects of this tradition, presenting fundamentally syntactic approaches to morphological structure. Yet Chomsky (1970), devoted to word formation, and Matthews (1972), devoted to inflection, laid the foundations for a return of morphology as a field of study in its own right and acceptance of the idea that at least some aspects of morphology cannot be reduced to other 'components' of language. Aronoff (1976) furthered arguments for morphology being fundamentally word-based, rather than morpheme-based, renewing what was in some ways a classical position refracted through the lens of Generative Grammar. Ultimately, three types of theories identified by Hockett (1954) – Item-and-Arrangement, Item-and-Process and Word-and-Paradigm – continue to echo in modern debates. Are morphologically complex words built up from morphemes (Item-and-Arrangement, Item-and-Process), or are they formed from already existing words (Word-and-Paradigm)? ('Item' here refers to morphemes.) Are morphological operations limited to the concatenation of lexically stored morphemes (Item-and-Arrangement) or is morphology characterised by a broader set of formal operations (Item-and-Process, Word-and-Paradigm)? These are still major issues in the field that engender many specific sub-issues.[3]

We are not neutral on these issues. For us, a crucial observation is that morphology is fundamentally *relational* – morphological structure serves to relate words to each other, with contrasts in meaning signalled by contrasting forms. This positions us firmly within the Word-and-Paradigm approach to morphology, which we will sometimes call the 'Word-Based Approach' in this chapter. This is a mainstream perspective for linguists who identify as 'working morphologists' (Anderson 2017: 11) but certainly not a universal one. Some of the chapters in this volume reflect a word-based philosophy – most notably, the chapters by Chuang, Kang, Luo and Baayen and by Beyersmann and Grainger – but the chapter by Marantz and Gwilliams, in particular, reflects a more syntactic and morpheme-based perspective on morphological structure.

Psycholinguists' and theoretical linguists' investigations of morphological structure tend to reflect different goals; the issues that concern theoretical morphologists do not always resonate in psychology, and vice versa. Yet both fields have a need for a better understanding of the other, as psycholinguistics has moved away from universalist models of language processing and grappled with ways in which lexical processing is 'tuned' to the morphological structure of a language, and morphologists have increasingly turned to language processing and learning to provide an explanation for morphological distributions.[4] In this chapter, we offer a brief introduction to the relational nature of morphology in some of its different aspects. While we point out a few connections with psycholinguistics, our goal is to offer our perspective on word structure as theoretical morphologists.

Terminology: Word forms, lexemes and lemmas

For (word-based) morphologists, different notions of word – specifically, *word forms, lexemes* and *lemmas* – need to be made precise, since the relations among these take centre stage in theorising (Matthews 1972). The most useful but also most difficult of the three concepts is the lexeme. Consider the English verb BE. This verb has many different forms: *am, is, are, was, were, been, being* and *be*.[5] BE has highly irregular forms which do not all have any (concrete) morpheme in common. We need to recognise eight suppletive stem forms, with *been* and *being* as the only ones built in a regular way on the root *be*. But there is a definite sense in which all eight of these forms belong together: they are all variant forms of a single verb. This single entity linguists call the lexeme BE,[6] while each distinct form is an inflected *word form* (or alternatively, *grammatical word*). Word forms are concrete in the sense that they have phonological form. In contrast, a lexeme is an abstract concept – the set of grammatical words that convey the same 'core' meaning of the word and occur in different morphosyntactic and morphosemantic contexts. A lexeme may have more inflected word forms than there are distinct phonological forms of the word. Almost all English verb lexemes have only four distinct forms. Take, for example, the lexeme LOOK: *look, looks, looked* and *looking*, but *looked* is used for both past tense and as a past participle (*I looked at her* vs. *I have looked at her*).[7] The lexeme LOOK thus has some homophonous word forms. In morphological terminology, it exhibits *syncretism* between past and past participle.

Linguists sometimes distinguish a lexeme from the dictionary-maker's *lemma* or *headword*. A single lemma may encompass many different senses. If we look up the verb RUN in the *Oxford English Dictionary Online* (OED), we will find that the single entry under the headword *run* has hundreds of senses and sub-senses, some unrelated: what does *running a marathon* have to do with *running a bath* or *running guns*? Yet all of these senses have exactly the same grammatical forms: *run, runs, running* and *ran*. This is an example of what Jackendoff and Audring (2020: 160–164) call the 'Same Verb Problem' (or more generally, the 'Same Word Problem'). In one way, *run* (a marathon), *run* (a bath) and *run* (guns) are the same word; they have the same morphological behaviour, including here the irregular past tense form *ran*, indicating that this is not simply a case of accidentally homophonous verbs. In another way, they are distinct words, since they have distinct semantic properties. Each distinct sense (or group of closely related senses, if they can be formally unified) is a distinct lexeme (Spencer 2013). The analytical challenge is, then, in capturing the common morphological properties of all the instances of a given lemma while also capturing the distinct semantic and constructional properties of multiple lexemes that share a lemma.

These uses of the terms *lexeme* and *lemma* do not fully align with how the same terms are used in corpus linguistics, computational linguistics and psycholinguistics. It is thus worth briefly pointing out some differences. In corpus and computational linguistics, the term *lemma* is used in a similar sense to the preceding definition. However, lemmas and lexemes are not systematically distinguished and the latter term does not seem to be used in any widespread way. In psycholinguistics, both notions also tend to be conflated under the term *lemma*, but the term *lexeme* is used most similarly to how morphologists use the term *word form*: to describe a phonological instantiation of a lemma (in the psycholinguistic use of the latter term; see, e.g., the production model of Levelt et al. [1999]). Our impression is that psycholinguists have in general not been attuned to the lexeme–lemma distinction, as we use the terms here.

The three-way distinction between *word forms, lexemes* and *lemmas* sets the foundation for how morphologists think about word structure.

Morphemes and the lexicon

The term *lexicon* is ancient, from the Greek λεξικόν βιβλίον 'word book'. A lexicon in the original sense was a dictionary, though the term was usually reserved for dictionaries of Greek, Hebrew, Syriac or Arabic, the non-Latin, hence exotic scholarly languages of the Renaissance. In linguistics, the first technical use of the term was in Leonard Bloomfield's highly influential book *Language*: 'The total stock of morphemes in a language is its lexicon' (Bloomfield 1933: 133). Bloomfield's definition assumes his own purely distributional recasting of Baudouin de Courtenay's morpheme: 'A morpheme is a recurrent (meaningful) form which cannot in turn be analyzed into smaller recurrent (meaningful) forms. Hence any unanalyzable word or formative is a morpheme' (Bloomfield 1933: 155). Bloomfield's theoretical conception of the lexicon of a language departed from non-technical usage in that it contained no words, only morphemes, which, following Saussure (1986 [1916]), he defined as unanalysable arbitrary signs.

Modern linguistic frameworks are, for the most part, wary of the traditional view of the morphemic sign as an atomic unit. Since Matthews (1972), the notion of the morphosyntactic feature has been key to morphological theorising. As the term suggests, morphosyntactic features are abstract syntactic entities that are realised by means of morphology. In English, for example, all main verbs must encode one of the abstract tense features, present and past. The features are realised concretely in various ways, depending on the person and number of the subject and on the individual verb. For the English verb BE, for example, the form *am* is obligatory if and only if the subject is first person singular (*I*) and the verb is in the present tense. Linguists say that this form realises the combination of features *first singular present* for this verb. The features themselves are abstract, being realised (i.e. instantiated by morphophonological form) in many possible ways, depending on their combination and the verb. Criticism of the morpheme as a Saussurean sign culminated in Anderson (1992), after which the definition was abandoned by almost all researchers in favour of a 'morphosyntactic feature realisation' approach.

Modern morphologists agree on this general picture. Interestingly, however, differences of terminology obscure what is a fundamental level of agreement on this point. At the same time, different understandings of the morphology–syntax interface continue to divide the field in meaningful ways into 'morpheme-based' and 'word-based' approaches, with consequences for the content and structure of the lexicon. In particular, theoretical models differ in the nature of the abstract syntactic representation that the morphology realises.

Adherents to Distributed Morphology (e.g. Gwilliams and Marantz, this volume) assume Chomsky's Minimalist programme (Chomsky 1993), which brings with it specific principles governing the syntax–morphology interface. Most importantly here, the terminal nodes of syntactic representations are individual morphosyntactic features, which are realised ('spelt out') by particular morphophonological forms post-syntactically. Distributed Morphologists elected to maintain the term *morpheme* for these representations, but these morphemes are not Saussurean signs because they lack any morphophonological form. They are, simply, morphosyntactic features. Prior to spell-out, various operations can apply that reorganise the tree structure that the syntax outputs; an operation might, for example, merge two terminal nodes into a single one to be realised by an indivisible morphophonological form (what Distributed Morphology calls a *vocabulary item*). Importantly here, this syntax–morphology interface has consequences for the lexicon: since spell-out occurs node-by-node, the lexicon (vocabulary) contains only the smallest units of morphological form, which are paired with the morphosyntactic features with which they are compatible. In other words, the lexicon contains something close to the traditional notion of a morpheme.[8]

Other morphologists tend to be more agnostic about the precise nature of the syntax and, correspondingly, to be less invested in the postulate that the morphology realises morphosyntactic features one-by-one. Some models posit that lexemes and sets of morphosyntactic features are realised jointly. This again has a consequence for the lexicon, reflecting a reversion to the traditional view that a lexicon must contain not just morphemes, but notable words too, and even phrases. In formal morphology, this reversion is rooted in the foundational principle of *compositionality*, which is usually attributed to the logician Gottlob Frege (though Frege never used that exact term), according to which the meaning of a complex expression must be predictable from the meanings of its parts and its structure. Any complex expression whose structure and meaning are not completely predictable must be listed in the lexicon. On this definition, the lexicon of a language will contain many complex words. Consider the two words *topic* and *topical*. The first is problematic for a simplistic (Structuralist) morpheme-based conception of the lexicon. It appears on its face to consist of two parts: *top* and *ic*. But whatever independent meanings we assign to these two parts based on their occurrence elsewhere, the meaning of *topic* itself is unanalysable. In turn, *topical*, though its meaning might appear at first glance to be compositionally derived from *topic* and *-al*, has a frequent specific meaning, 'of or pertaining to the topics of the day', which cannot be derived compositionally. Thus, both *topic* and *topical* must be listed in the lexicon of a speaker of English who knows these words.

This same criterion dictates that units larger than words (phrases and even sentences) will be listed in the lexicon if their meanings are not predictable. Idioms like *kick the bucket* or *over the hill* fall into this category, as do stock expressions like *A rose by any other name would smell as sweet.* This is a return, at least in spirit, to the original purpose of a practical lexicon, which was to list words that a reader may not know. The first dictionary of English (Cawdrey 1617 [1604]) bears a very long title, which begins with the words *A Table Alphabetical* and includes the phrase *Hard Usuall English Words*.

Differently from the task of the dictionary-maker, however, most morphologists are interested in how speakers cognitively represent words and constructions.[9] This makes the *mental* lexicon a focus for many theoretical morphologists, but often not in quite the same ways as for psycholinguists. In behavioural studies, robust stem/word frequency effects during morphological processing (e.g. in priming lexical decision tasks) have been taken as indicating a substantially word-based lexicon containing even many regularly derived complex words.[10] This evidence reflects a focus on how forms are cognitively processed, and less so on form–meaning relations. A connection between word frequency effects and semantic compositionality has long been recognised, however. High-frequency words are more likely to develop semantic opacity (non-compositionality) as a byproduct of whole-word storage in the mental lexicon, a process referred to as *lexicalisation* (Aronoff and Anshen 1998). Both types of evidence thus seem to tap into the same fundamental truth about the lexicon. Moreover, it is increasingly possible to compare them. Semantic compositionality is difficult to investigate at scale using the traditional linguistic methods of elicitation and metalinguistic judgements of acceptability. Until recently, discussion of lexicalisation and semantic non-compositionality, while long-standing in the morphological literature, tended to be based on generalisations drawn from anecdotal examples. However, distributional semantic models drawn from computational linguistics have opened new possibilities for the statistical and quantitative investigation of inflectional and word-formation semantics in ways that can be explicitly compared with the results of behavioural studies. For studies applying a distributional semantic approach to morphological theory, see Bonami and Paperno (2018), Lapesa et al. (2018) and Marelli and Baroni (2015), and for ones applying it to morphological processing, see Amenta et al. (2020) and Marelli (this volume).

At the same time, the questions about the lexicon that are of interest to most linguists continue to be distinct from those of interest to most psychologists. Despite some exploration of implicitly paradigmatic factors in morphological processing, such as morphological family size, psycholinguists have generally been interested primarily in the units of morphological processing and the lexicon – words and/vs. morphemes – than in how these are related. In contrast, morphologists in the Word-and-Paradigm tradition are primarily interested in the structured associative (paradigmatic) connections among elements in the lexicon and the generalisations (rules) that emerge from those connections. In other words, they are generally far more interested in Paradigm than in Word. In what follows, we consider some specific ways in which structured connections among elements in the lexicon have consequences for morphological organisation, starting with the paradigm.

Paradigms

The term *paradigm* dates back to the earliest Greek grammarians, over two millennia ago. The Greek word παράδειγμα means 'pattern, example'. In traditional school grammar, it refers to a table showing all the inflected forms of a particular verb, noun or adjective, which serves as a model for other words of the same class. The traditional paradigm remains the bane of language students to this day.

The linguist's paradigm is a bit more abstract. While linguists may refer to the set of grammatical words of a lexeme as its paradigm, more often the term is used to describe relations among word forms at a level of representation that abstracts away from particular exponents. Consider the distribution of Spanish verb forms shown in Table 2.1. SENTIR 'feel', PENSAR 'think' and MOVER 'move' have the same distribution of stem forms, which is shown by grey cell shading, but in the first two the stem alternation is *ie* ~ *e* while in MOVER it is *ue* ~ *o*. The distribution of stem forms among paradigm cells (each set of grammatical properties defines a cell) is thus to some degree independent of the particular alternation. Moreover, in the history of Spanish speakers extended the pattern to suppletive forms as well. In Old Spanish, the present indicative forms of IRE 'go' were *vo, vas, va, imos, ides* and *van*, showing full stem suppletion with the same distribution as in Table 2.1.[11] The fact that the resulting paradigm replicated an existing distribution of stem alternation shows the tendency of speakers to make generalisations about distributions of word forms within paradigms at a greater level of abstraction than the forms themselves, specifically at the level of grammatical properties (Maiden 2005).

TABLE 2.1. Present indicative word forms of select Spanish verb conjugation classes; in each row, the cells shaded in grey share a stem alternation.

LEXEME	*GLOSS*	*PRS.1SG*	*PRS.2SG*	*PRS.3SG*	*PRS.1PL*	*PRS.2PL*	*PRS.3PL*
CANTAR	'sing'	canto	cantas	canta	cantamos	cantáis	cantan
SUBIR	'rise'	subo	subes	sube	subimos	subís	suben
PENSAR	'think'	pienso	piensas	piensa	pensamos	pensáis	piensan
SENTIR	'feel'	siento	sientes	siente	sentimos	sentís	sienten
MOVER	'move'	muevo	mueves	mueve	movemos	movéis	mueven

Generalisations of this sort have been central to morphological theorising, informing two related but ultimately distinct theoretical choices. The first has to do with the extent to which morphological structure is governed by (at least some) principles that are separate from those of both syntax and phonology, which is referred to as *autonomous morphology*. The second has to do with whether morphological structure is characterised by paradigmatic relations. Since paradigmatic structure is a kind of autonomous morphological structure, we focus here on paradigmatic relations as a stand-in for a broader range of issues related to the autonomous nature of morphology.

The term *paradigmatic relations* refers to relationships among words or other elements that are substitutional in nature, for example, the relationship between the stem forms *piens-* and *pens-* for the verb PENSAR, or between *go-* and *wen-* for GO. Paradigmatic relations contrast with *syntagmatic relations*, which are combinatorial in nature. For example, the stem *piens-* and the first person singular suffix *-o* are syntagmatically related. It is clear that syntagmatic generalisations are part of speakers' implicit knowledge of morphological structure. To take a derivational example, adjectives ending in *-able* have a strong tendency to form abstract nouns with *-ity*, even though *-ness* is more productive than *-ity* overall. Paradigmatic relations, however, have been the subject of debate.

Linguists who seek to maximise the similarity of morphology to syntax have often sought to eliminate paradigmatic relations as theoretical postulates. Here again, the frameworks of Distributed Morphology (Embick 2015; Halle 1997; Halle and Marantz 1993) and Nanosyntax (Baunaz et al. 2018; Caha 2009) are most notable. Linguists who are not committed *a priori* to a syntactic approach, however, have no particular incentive to reduce morphology to syntagmatic generalisations, and they favour the greater empirical adequacy afforded by direct statements in the grammar about the ways in which word forms are paradigmatically related. This approach is central to a range of Formalist and Functionalist models, including Bybee's Network Model (Bybee 1985), A-morphous Morphology (Anderson 1992), Paradigm Function Morphology (Stump 2001; Stump 2016), Network Morphology (Brown and Hippisley 2012; Corbett and Fraser 1993), Information-based Morphology (Bonami and Crysmann 2016; Crysmann and Bonami 2016), Construction Morphology (Booij 2010), and Relational Morphology (Jackendoff and Audring 2020).

Perhaps the most important evidence for paradigmatic relations in the grammar comes from syncretism. As noted above, syncretism is inflectional homophony. Table 2.2 shows an example from Russian, in which the accusative plural of nouns (also adjectives, not shown) has the same form as the nominative plural when the noun refers to an inanimate entity (e.g. *zavod-y* 'factories'), but has the same form as the genitive plural when the noun has an animate referent (e.g. *student-ov* 'students'). The pattern of syncretism repeats across noun declension classes but is instantiated by different affixes in different classes. An important question for morphologists is how to formally capture such patterns of identity.

Examples of this sort have been the subject of lengthy debate, and the technical details are too complex to present here,[12] but word-based morphologists posit generalisations of the sort 'the accusative plural has the same form as the genitive plural in animate nouns' – in other words, direct statements about the relations holding among paradigm cells (Baerman et al. 2005). Frameworks that allow only syntagmatic generalisations, thus disallowing simple statements of this sort, are motivated by a desire to maximise the similarity of morphology to syntax and/or to maintain greater restrictiveness in the theory. In linguistics, a theory is often considered to be adequate based not only on its ability to account for empirically observed patterns in language data, but, equally importantly, also on its ability to correctly predict the non-existence of ungrammatical patterns; this latter part is what is meant by *restrictiveness*. Paradigmatic generalisations can, by their nature, account for an almost unlimited variety of syncretisms. For morphologists who consider restrictiveness to be a core metric against which a theory should be evaluated (not all do), the straightforward nature of paradigmatic generalisations must therefore be weighed against a loss of restrictiveness, often to the conclusion that paradigmatic relations come at too high a cost. However, the additional mechanisms needed for purely syntagmatic analyses of some kinds of syncretism may themselves reduce the restrictiveness of a theory (Baerman 2004: 821–823; Carstairs-McCarthy 1998). Moreover, there are questions about whether a solely syntagmatic approach is adequate to the range of syncretic phenomena found in the world's languages (Baerman et al. 2005). In our view, syncretism offers powerful evidence that morphological structure is fundamentally characterised by paradigmatic relations.

TABLE 2.2. Select plural word forms of Russian nouns, showing three of its four major declension classes; syncretic word forms in each row are shaded.

CLASS	*EXAMPLE*	*NOM PL*	*ACC PL*	*GEN PL*
I INAN	ZAVOD 'factory'	zavod-y	zavod-y	zavod-ov
I ANIM	STUDENT 'student'	student-y	student-ov	student-ov
III INAN	KOST 'bone'	kost-i	kost-i	kost-ej
III ANIM	MAT 'mother'	mater-i	mater-ej	mater-ej
IV INAN	MESTO 'place'	mest-a	mest-a	mest
IV ANIM	ČUDOVIŠČE 'monster'	čudovišč-a	čudovišč	čudovišč

In derivation, the situation is more complicated, but evidence for paradigmatic relations as generalisations of the grammar can be found here as well. For instance, some English noun-adjective pairs seem to be built on a verb stem, but without the verb existing (Aronoff 1976: 29): *incision-incisive* (**incise), emulsion-emulsive* (**emulse), gustation-gustatory* (**gustate), illusion-illusory* (**illude*) and others. The derived nouns and adjectives were borrowed from French as full words; in a sense, they are thus quirks of history. But the semantics of the words (and other facts) suggest that speakers relate the adjectives and nouns directly, even when the corresponding verb does exist. For instance, in the triplet *induce, induction, inductive* the noun and adjective can refer to a kind of reasoning in one of their meanings, but the verb cannot (Aronoff 1976: 30). This indicates that nouns with the suffix *-ion* serve as bases for adjectives with *-ive* and *-ory*, rather than nouns and adjectives being built independently on a verb base. Derivational paradigms have garnered significant interest recently; see Hathout and Namer (2019) and other articles in the same issue.

Recent work has also renewed interest in surface word forms and how they are related. Work on the role of *principal parts* – a set of word forms from which all the inflected forms of a lexeme can be predicted – has in some ways brought the field full circle back to the paradigm of Greek grammarians and school grammars. But instead of being a practical tool for the language learner and grammarian, principal parts are being quantified set-theoretically (Stump and Finkel 2013) or information-theoretically (Ackerman and Malouf 2013) and used for typological investigation, examining cross-linguistic diversity in how morphological systems are organised. A surfacist Word-and-Paradigm approach is also being applied to theoretical modelling under the term *abstractive morphology* (Blevins 2006). Abstractive models are *ex hypothesi* surfacist, without the hierarchically organised levels of abstract structure – phonemes, morphemes, stems – that are a core legacy of the Bloomfieldian Structuralist approach to linguistics.

Some scholars (e.g. Baayen et al. 2011; Blevins et al. 2016) have interpreted discriminative learning models along these lines as mathematically explicit and psycholinguistically informed implementations of surfacist Word-and-Paradigm principles. The focus here is on Word rather than on Paradigm, however. Discriminative learning rejects the idea that morphemes are independent objects of the morphology; rather, relations are strictly between semantic units on the one hand and phonemic or graphemic units on the other. Paradigmatic relations of the sort highlighted in this section are thus not a property of such models. Chuang, Kang, Luo and Baayen (this volume) and Crepaldi (this volume) discuss discriminative learning.

In summary, evidence that speakers robustly make generalisations about paradigmatically related words at both surface and abstract (non-form) levels is consistent with the idea of the lexicon as consisting primarily of word-based lexical entries. Structured connections among these lexical entries constitute the morphological structure of a language. However, as the attentive reader can probably discern, this fundamentally paradigmatic view of morphology raises questions for the traditional distinction between grammar and lexicon. We now turn to this issue.

The rule–list dichotomy

In the 20th century, a major inheritance to Generative Grammar from Structuralism was the hypothesis of a strong separation between lexicon and grammar. In their book, Di Sciullo and Williams use the metaphor of a prison to evocatively capture this division of language into separate architectural components: the lexicon 'is incredibly boring by its very nature … Those objects that it does contain are there because they fail to conform to interesting laws. The lexicon is like a prison – it contains only the lawless, and the only thing its inmates have in common is lawlessness' (Di Sciullo and Williams 1987: 3). This view positioned grammar (rules) as the domain of systematicity and structure and thus the *raison d'être* of linguistic study.

Cracks in this prison wall separating grammar from lexicon began to appear with Chomsky (1970), who observed that in English some nominalisations from verbs are fully regular in their semantics and morphophonology and fully productive (most notably gerund *-ing*, as in *Taylor's criticising was unfair*), while others are less predictable (e.g. *-ment* as in *government*). Given the fully productive nature of syntax, Chomsky concluded that the unpredictable forms must be generated 'in the lexicon' rather than in the syntax, thereby expanding the power of the lexicon and assigning it some Generative responsibility. Lexicalist models have grown from this seed, and, most relevantly here, so has an understanding (in most morphological theories) of the lexicon not as an unstructured list of lawless words and morphemes, but as a highly structured network of paradigmatic relations among lexical entries.

Taking this view to its logical extreme, the grammar becomes a set of second-order generalisations made over lexical entries and the first-order paradigmatic relations connecting them. Morphemes become emergent structures – abstractions over word instances that specify the elements of form and meaning that are common to those words, rather than theoretical primitives. Not all theories, not even all word-based theories, hold such an extreme view of the fundamental blurriness of the grammar–lexicon relationship, but this view of grammar as almost subsumed to lexicon is a position strongly advocated for in Bybee's Network Model (Bybee 1988), Construction Morphology (Booij 2010) and Relational Morphology (Jackendoff and Audring 2020). Ultimately, to the extent that much of morphological structure is 'in the lexicon', this is an acknowledgement that the rule–list (grammar–lexicon) dichotomy is false.

Productivity

Productivity is particularly informative about the intersection of morphological theory and cognitive processes, and is another domain in which structured relations among elements in the lexicon constitute morphological organisation.

The productivity of a morphological pattern is the likelihood of it being used to coin new words of a language. A morphological pattern that has a broad meaning and which can attach to a variety of different kinds of bases – like English *-ness*, which forms nouns meaning, roughly, 'quality of' and which frequently combines with adjective bases (*truthiness*),[13] but also noun bases (*languageness*),[14] and even whole phrases (*here-and-now-ness*) – might add many new words to a language. An affix that has a more specific meaning – for example, *-ology* as in *Albanology, dendrology* – or that imposes many restrictions on bases with which it will combine may contribute new words at a lower rate. At the same time, *-ology* can readily be used to coin words for new fields of academic study. The broad concept of productivity is thus cashed out in terms of more specific questions: How much does a given morphological pattern contribute to the overall expansion of a language's or an individual's vocabulary? If a word with a given meaning needs to be coined, what morphological pattern will be used? The different specific notions of productivity implied by these (and other) questions are not necessarily correlated.

For morphologists, the importance of productivity lies in the fact that the productivity of morphological patterns varies widely. Indeed, the need to pay attention to productivity is a primary factor making morphology different from other subfields of linguistics. In the area of syntax, words combine into phrases with virtually universal productivity; this is the motivation for the very notion of phrase-structure grammar. Speakers may notice new words that they encounter (although probably not as much as they may think they do), dictionaries record new words, and there are contests to select the best new words, but in general speakers have no awareness of which sentences they have or have not heard before.

The obvious question is why morphology is so different from syntax in this respect. Why do morphological patterns differ widely in how productive they are? In a broad sense, the answer is that morphology is more closely tied to the content and organisation of the lexicon than syntax is. Work on derivational productivity, stemming from Hay and Baayen (2002), has emphasised the role of morphological processing in productivity. Hay and Baayen demonstrated that there is a strong correlation between an English derivational affix's productivity and the likelihood of that affix being parsed out from its base during lexical processing, as predicted by a parallel dual-route (race) model.[15] They posited a causal connection: productivity is a function of the activation level of an affix, which is itself a function of the number of times its lexical entry is activated during morphological processing. Whole-word access bleeds potential activations, and since high-frequency words are likely to be accessed whole, affixes that occur primarily in lexemes with high token frequency – like *-th* as in *length, strength* – are unproductive or minimally productive as a result. The type frequency of a morphological pattern is also strongly positively correlated with its productivity (Bybee 1995), perhaps because the more unique words there are that reinforce the target morphological pattern, the more readily that pattern is recognisable and the greater the activation strength of its representation in the lexicon will be.

By and large, the same factors apply also in the area of inflection. Type frequency is certainly important to the productivity of inflectional patterns (e.g. Albright and Hayes 2002). Inflectional productivity, however, additionally highlights the importance of relational structure. Irregular past tense verbs in English – surely one of the most thoroughly investigated morphological phenomena – maintain their irregularity through a combination of the high token frequency of the relevant lexemes and being clustered in the lexicon in morphophonological 'neighbourhoods'. To take a single example, verbs in which the past tense is the same as the base form – for us, this set includes *beat, bet, bid, burst, cost, cut, fit, hit, hurt, knit, let, put, quit, rid, set, shed, shut, slit, spit, split, spread* and *wed*, among others – all end in [t] or [d] and tend to be monosyllabic. The key observation is that the phonological similarity of the words reinforces their irregular inflectional pattern, allowing them to resist regularisation to *-ed*.[16] Moreover, sometimes generalisations about neighbourhoods must be formulated in terms of complex words (i.e. the 'outputs' of a morphological process in some Generative sense); for instance, HANG and STRIKE have different vowels in their basic (present tense) form, but have the same morphological pattern in past tense (*hung, struck*). They thus constitute a more coherent morphophonological class in past tense than in their basic ('input' or 'underlying') form. Called *product-oriented generalisations* (Bybee and Moder 1983), such examples must be understood as a function of the structured connections that speakers make among morphologically complex words in the lexicon.

The structured associations connecting lexical entries are thus of central importance to productivity. In historical linguistics, the ways in which words influence similar words (their neighbours) has been discussed under the term *analogy* since at least the time of the Neogrammarians of the late 19th century, but the development of quantitative methods for measuring neighbourhood structure has begun to make it possible to examine this structure in a more precise and detailed way.

Competition between patterns

One of the most vexing properties of all human languages is the presence of a variety of forms with the same meaning. This is especially true in morphology. In English, we find pairs of suffixes like *-ness* and *-ity*, *-ive* and *-ory*, *-hood* and *-ship*, where both suffixes appear to have the same function: *productiveness* and *productivity, conclusive* and *conclusory, apprenticehood* and *apprenticeship* are all found. Sometimes there are subtle differences between the rival members of the pair, in either distribution or meaning, but more often people are hard put to distinguish them.

Both linguists and psychologists have long studied these and similar cases in terms of relative productivity. In the last decade, morphologists have come to see that underlying the interactions among such rivals is a principle not of language but of any complex system: competitive exclusion. Competition is fundamental to Darwinian biology. In its most simplistic form, it is expressed in the slogan 'survival of the fittest' (the one that fits the environment best) at the level of both species and individual. Gause's (1934) principle of competitive exclusion states that two species competing for exactly the same resources cannot both survive: one will drive out the other, which will either become extinct or find its own niche. The principle was refined mathematically by Levin (1970).

If we regard distinct words as individuals and distinct morphological patterns as species, then Gause's law predicts that apparently synonymous words must become distinct in their meaning if both are to survive and that rival patterns will thrive in distinct morphological, phonological, syntactic, syntactic or pragmatic environments. Aronoff (2019) provides numerous cases showing that this is indeed so. Thus, while words ending in *-ness* may be more type-frequent overall, *-ity* will more readily attach to words ending in *-(a)ble* (*ably/ability/?ableness*). These niches may extend to social groups: Most people prefer the word *biological* over *biologic*, but in the biological and medical fields *biologic* is much more prevalent. The same is true of word pairs like *psychological* and *psychologic*. The full distribution of the pairs *Xic* and *Xical* is complex, but it is mostly well behaved and usually adheres to morphological niches. For example, there are many more adjectives of the form *Xistic* than words of the form *Xistical*, and the former are by and large more token-frequent. Overall, though, the distribution follows the principle of competitive exclusion.

This view of morphological competition fits in very well with the overall picture of morphology that we have painted. Precisely how it can be cashed out experimentally remains to be seen.

Conclusion

The picture that emerges from different areas of morphological structure is one in which a word-based lexicon and structured relations among lexical entries are the foundation for much of morphological organisation, ranging from explicitly paradigmatic generalisations (e.g. statements of word form identity in cases of syncretism) to productivity to morphological competition and more. This is not to deny that speakers make morpheme-like generalisations; in fact, it would be surprising if speakers did *not* make such generalisations when relations recur in parallel fashion among many different words. But treating morphology as fundamentally *relational* in nature assigns words (word forms, lexemes and lemmas) a primary status and morpheme generalisations a secondary one. This upends a major legacy of Structuralist linguistics: the postulate that complex words are built out of atomic meaningful elements.

While this reordering of the importance of words and morphemes, with all of its further on consequences, has become the mainstream position for linguists who focus primarily on morphology, it is certainly true that not all modern theories accept this reordering, particularly ones that are committed to maximising the similarity of morphology to syntax for independent reasons, or which value parsimony of description. (Word-based lexicons are inherently highly redundant.) Even within word-based theories, there are of course differences such as in how directly morphology is 'in the lexicon', in whether morphological bases are words (abstractive/surfacist approaches) or stems (constructive/abstract approaches), in whether a theory is formalist or functionalist/emergentist and, increasingly, in whether it is set-theoretic/deterministic or quantitative/probabilistic in orientation. The field of morphology, at least as much as the fields of syntax and phonology and perhaps more so, has thus grown to be characterised by a rich diversity of models. The observation that morphological structure is relational in nature is thus simply the starting point for investigation, and how this is cashed out in terms of specific theories of morphology is an issue of active debate.

In this chapter, we have been able to give only a cursory overview of issues that arise for morphological description and theory. We have tried to focus on those that we think are the most revealing about the nature of morphological structure and those likely to be of the most interest to psychologists. We have also tried to give pointers to some of the major current theories and situate them relative to each other. For the reader who wants to dive deeper into the topics and theoretical models mentioned, several excellent handbooks have been published in recent years, including Audring and Masini (2019) and Hippisley and Stump (2016).

Notes

1 Both authors contributed equally to this chapter.
2 We use Glottolog codes to identify languages that might not be familiar to the reader. See, e.g., https://glottolog.org/resource/languoid/id/kala1399 (accessed 15 February 2021).
3 For an older but still useful discussion of the major conceptual choices in a theory of morphology, see Zwicky (1992). A more recent overview of the choices that define particular theories is available in Stewart (2015).
4 For a discussion of some of the ways in which psycholinguistics, morphological theory, and typology intersect, see Sims et al. (2022).
5 While this is a large number of forms for English, it is small on the scale of the world's languages. In the Nakh-Daghestanian language Archi (arch1244), spoken in the Dagestan region of Russia, verb lexemes can in principle have more than one million grammatical words each (Kibrik 1998).
6 Notice the use of SMALL CAPS for lexemes, a common (but not universal) practice among morphologists, particularly when it is important to distinguish lexemes from wordforms. By convention, wordforms are given in *italics*, although italics have other uses as well.
7 A distinction between past tense and past participle as grammatical properties of the language is motivated analytically by the fact that in many other English verbs, the forms are not the same, e.g. *ate* and *(has) eaten*, or *ran* and *(has) run*. For a discussion of analytic criteria for determining the inflectional properties of a language, see Comrie (1986) and Corbett (2011).
8 One issue here is that it can be difficult to tease apart realisationalism as a principle from the question of the realisation of individual morphosyntactic values (abstract morphemes) as units vs. larger sets of morphosyntactic values. Here, we find much in common with Gwilliams and Marantz's (this volume) view about evidence for realisationalism, although not necessarily as evidence for abstract morphemes uniquely.
9 Some linguists seek to model languages as purely formal systems, rather than as cognitive ones. But this position is not extremely common among morphologists, perhaps because the question of productivity is virtually unavoidable in morphology and productivity is closely connected to human cognition, as discussed briefly below.
10 For a succinct overview discussion of the effects of stem/word frequency and other factors in morphological processing, see Amenta and Crepaldi (2012). See also Taft's contribution to this book (Chapter 11) for a brief discussion of why a psychologically realistic theory of visual word identification might require a lexicon that is composed of all existing words in a language, either simple or complex. Interpretation of word frequency effects is complicated (see Gagné and Spalding [2019] and Plag and Balling [2020] for an overview discussion). One issue we are glossing over has to do with differences between symbolic and sub-symbolic models of processing. The latter do not have morphemes (or words!) as primitives, which obviously complicates simplistic

interpretation of the mental lexicon as containing these units. However, representations corresponding to both words and morphemes can be emergent structures, where a given phonological string is a reliable cue to a given meaning (Rueckl and Raveh 1999). Perhaps the most conservative conclusion is that behavioural studies provide evidence that lexical access does not always proceed via decomposition into morpheme-like units and can instead involve larger chunks of form.

11 The Old Spanish forms resulted from the merger of two separate lexemes (Maiden 2005). (The word forms of the English verb GO, with past tense *went*, historically from the verb lexeme WEND, has similar origins.) The alternation was subsequently levelled in this word. Modern Spanish has present indicative forms *voy, vas, va, vamos, vais* and *van*.

12 See Baerman (2004) for a discussion of the theoretical issues raised by syncretism in Russian nouns and adjectives.

13 The word *truthiness* is particularly interesting because it was coined and popularised by Stephen Colbert in 2005 on his US television show *The Colbert Report*. The Google Ngrams corpus (https://books.google.com/ngrams) and the Corpus of Contemporary American English (COCA, https://www.english-corpora.org/coca/) document the appearance of the word in that year. The OED includes some attestations of *truthiness* as early as 1832, but with a different meaning (synonymous with *truthfulness*). It is rare that we can pinpoint the coining of a new word with such precision.

14 An example from COCA: 'Or, to put the point in a different way, literary language is a shift in modes of representation, from a mode that treats language as a more or less transparent medium to a mode that underscores the medium of language and the work that medium does, what Joel Fineman has called "the languageness of language"'.

15 Specifically, they measure category-conditioned productivity (Baayen 2001), which is an estimate of the likelihood that an observed instance of a word exhibiting a target morphological process will be newly coined.

16 Sims (2015: 208–248) argues that the same kind of neighbourhood effect is also found for paradigmatic gaps in Russian verbs. Paradigmatic gaps are missing word forms – situations in which there is no form that speakers will accept, where one is expected. For example, Russian speakers reject all possible first person singular forms of UBEDIT' 'to convince'; there is no way to use this verb to say 'I will convince (you)!', although it is perfectly possible to say 'We will convince (you)!' (*ubedim*). That gaps can be sensitive to morphophonological neighbourhoods might initially seem surprising – gaps are, after all, the *lack* of any morphophonological form – but it speaks to how pervasively speakers attune to generalisations about the morphological properties of similar words in ways that are fundamentally analogical.

References

Ackerman, Farrell, and Robert Malouf. 2013. Morphological organization: The Low Conditional Entropy Conjecture. *Language* 89 (3): 429–464. doi:10.1353/lan.2013.0054.

Albright, Adam, and Bruce Hayes. 2002. Modeling English past tense intuitions with minimal generalization. In *Proceedings of the Sixth Meeting of the Association for Computational Linguistics Special Interest Group in Computational Phonology in Philadelphia, July 2002*, edited by Michael Maxwell, 58–69. Cambridge, MA: ACL.

Amenta, Simona, and Davide Crepaldi. 2012. Morphological processing as we know it: An analytical review of morphological effects in visual word identification. *Frontiers in Psychology* 3: Article232. doi:10.3389/fpsyg.2012.00232.

Amenta, Simona, Fritz Günther and Marco Marelli. 2020. A (distributional) semantic perspective on the processing of morphologically complex words. *The Mental Lexicon* 15 (1): 62–78. doi:10.1075/ml.00014.ame.

Anderson, Stephen R. 1992. *A-morphous morphology*. Cambridge: Cambridge University Press.

Anderson, Stephen R. 2017. Words and paradigms: Peter H. Matthews and the development of morphological theory. *Transactions of the Philological Society* 115 (1): 1–13. doi:10.1111/1467-968X.12090.

Aronoff, Mark. 1976. *Word formation in Generative grammar*. Cambridge, MA: MIT Press.

Aronoff, Mark. 2019. Competitors and alternants in linguistic morphology. In *Competition in inflection and word formation*, edited by Franz Rainer, Francesco Gardani, Wolfgang Dressler and Hans-Christian Luschützky, 39–66. Berlin: Springer.

Aronoff, Mark, and Frank Anshen. 1998. Morphology and the lexicon: Lexicalization and productivity. In *The handbook of morphology*, edited by Andrew Spencer and Arnold M. Zwicky, 237–247. Malden, MA: Blackwell.

Audring, Jenny, and Francesca Masini, eds. 2019. *Oxford handbook of morphological theory*. Oxford: Oxford University Press.

Baayen, R. Harald. 2001. *Word frequency distributions*. Dordrecht: Kluwer.

Baayen, R. Harald, Petar Milin, Dušica Filipović Đurđević, PeterHendrix and Marco Marelli. 2011. An amorphous model for morphological processing in visual comprehension based on naive discriminative learning. *Psychological Review* 118 (3): 438–481. doi:10.1037/a0023851.

Baerman, Matthew. 2004. Directionality and (un)natural classes in syncretism. *Language* 80 (4): 807–827. doi:10.1353/lan.2004.0163.

Baerman, Matthew, Dunstan Brown and Greville Corbett. 2005. *The syntax–morphology interface: A study of syncretism*. Cambridge: Cambridge University Press.

Baudouin de Courtenay, Jan. 1972. *A Baudouin de Courtenay anthology: The beginnings of structural linguistics*. Translated by Edward Stankiewicz. Bloomington, IN: Indiana University Press.

Baunaz, Lena, Karen De Clercq, Liliane Haegeman and Eric Lander, eds. 2018. *Exploring Nanosyntax*. Oxford: Oxford University Press.

Baunaz, Lena, and Eric Lander. 2018. Nanosyntax: The basics. In *Exploring nanosyntax*, edited by Lena Baunaz, Karen De Clercq, Liliane Haegeman and Eric Lander, 3–56. New York: Oxford University Press.

Blevins, James P. 2006. Word-based morphology. *Journal of Linguistics* 42 (3): 531–573.

Blevins, James P., Farrell Ackerman, Robert Malouf and Michael Ramscar. 2016. Morphology as an adaptive discriminative system. In *Morphological metatheory*, edited by Daniel Siddiqi and Heidi Harley, 271–301. Amsterdam: John Benjamins.

Bloomfield, Leonard. 1933. *Language*. New York: H. Holt and Company.

Bonami, Olivier, and Berthold Crysmann. 2016. Morphology in constraint-based lexical approaches to grammar. In *The Cambridge handbook of morphology*, edited by Andrew Hippisley and Gregory Stump, 609–656. Cambridge: Cambridge University Press.

Bonami, Olivier, and Denis Paperno. 2018. Inflection vs. derivation in a distributional vector space. *Lingue e Linguaggio* 17: 173–195. doi:10.1037/a0039267.

Booij, Geert. 2010. *Construction morphology*. Oxford: Oxford University Press.

Brown, Dunstan, and Andrew Hippisley. 2012. *Network Morphology: A defaults-based theory of word structure*. Cambridge: Cambridge University Press.

Bybee, Joan. 1985. *Morphology: A study of the relation between meaning and form*. Philadelphia: John Benjamins.

Bybee, Joan. 1988. Morphology as lexical organization. In *Theoretical morphology: Approaches in modern linguistics*, edited by Michael Hammond and Michael Noonan, 119–142. San Diego, CA: Academic Press.

Bybee, Joan. 1995. Regular morphology and the lexicon. *Language and Cognitive Processes* 10 (5): 425–455. doi:10.1080/01690969508407111.

Bybee, Joan, and Carol Moder. 1983. Morphological classes as natural categories. *Language* 59 (2): 251–270. doi:10.2307/413574.

Caha, Pavel. 2009. *The Nanosyntax of case*. PhD dissertation, University of Tromsø.
Carstairs-McCarthy, Andrew. 1998. Comments on the paper by Noyer. In *Morphology and its relation to phonology and syntax*, edited by Steven G. Lapointe, Diane K. Brentari and Patrick M. Farrell, 286–301. Stanford, CA: CSLI.
Cawdrey, Robert. 1617 [1604]. *A table alphabeticall, contayning and teaching the true writing and understanding of hard usuall English words, borrowed from the Hebrew, Greeke, Latine, or French &c*. London: T S for Edmund Weauer.
Chomsky, Noam. 1957. *Syntactic structures*. 'S-Gravenhage: Mouton.
Chomsky, Noam. 1965. *Aspects of the theory of syntax*. Cambridge, MA: MIT Press.
Chomsky, Noam. 1970. Remarks on nominalization. In *Readings in English transformational grammar*, edited by Roderick Jacobs and Peter Rosenbaum, 184–221. Waltham, MA: Ginn.
Comrie, Bernard. 1986. On delimiting cases. In *Case in Slavic*, edited by Richard D. Brecht and James S. Levine, 86–106. Columbus, OH: Slavica.
Corbett, Greville G. 2011. The penumbra of morphosyntactic feature systems. *Morphology* 21 (2): 445–480. doi:10.1007/s11525-010-9171-4.
Corbett, Greville G., and Norman Fraser. 1993. Network Morphology: A DATR account of Russian nominal inflection. *Journal of Linguistics* 29 (1): 113–142. doi:10.1017/S0022226700000074.
Crysmann, Berthold, and Olivier Bonami. 2016. Variable morphotactics in Information-based Morphology. *Journal of Linguistics* 52 (2): 311–374. doi:10.1017/S0022226715000018.
Di Sciullo, Anna Maria, and Edwin Williams. 1987. *On the definition of word*. Cambridge: Cambridge University Press.
Embick, David. 2015. *The morpheme: A theoretical introduction*. Berlin: De Gruyter Mouton.
Gagné, Christina L., and Thomas L. Spalding. 2019. Morphological theory and psycholinguistics. In *The Oxford handbook of morphological theory*, 541–553. Oxford: Oxford University Press.
Gause, Georgy Frantisevich. 1934. *The struggle for existence*. Baltimore: Williams and Wilkins.
Halle, Morris. 1997. Distributed Morphology: Impoverishment and fission. *MIT Working Papers in Linguistics* 30: 425–449. doi:10.1075/cilt.202.07hal.
Halle, Morris, and Alex Marantz. 1993. Distributed morphology and the pieces of inflection. In *The view from Building 20*, edited by Kenneth Hale and Samuel Jay Keyser, 111–176. Cambridge, MA: MIT Press.
Harris, Zellig S. 1942. Morpheme alternants in linguistic analysis. *Language* 18 (3): 169–180. doi:10.2307/409550.
Hathout, Nabil, and Fiammetta Namer. 2019. Paradigms in word formation: What are we up to? *Morphology* 29 (3): 153–165. doi:10.1007/s11525-019-09344-3.
Hay, Jennifer, and R. Harald Baayen. 2002. Parsing and productivity. In *Yearbook of morphology 2001*, edited by Geert Booij and Jaap Van Marle, 203–235. Dordrecht: Kluwer.
Hippisley, Andrew, and Gregory T. Stump, eds. 2016. *The Cambridge handbook of morphology*. Cambridge: Cambridge University Press.
Hockett, Charles F. 1947. Problems of morphemic analysis. *Language* 23 (4): 321–343. doi:10.2307/410295.
Hockett, Charles F. 1954. Two models of grammatical description. *Word* 10 (2–3): 210–234. doi:10.1080/00437956.1954.11659524.
Jackendoff, Ray, and Jenny Audring. 2020. *The texture of the lexicon: Relational Morphology and the Parallel Architecture*. Oxford: Oxford University Press.
Kibrik, Aleksander E. 1998. Archi. In *The handbook of morphology*, edited by Andrew Spencer and Arnold M. Zwicky, 455–476. Maiden, MA: Blackwell.
Lapesa, Gabriella, Lea Kawaletz, Ingo Plag, Marios Andreou, Max Kisselew and Sebastian Padó. 2018. Disambiguation of newly derived nominalizations in context: A Distributional Semantics approach. *Word Structure* 11 (3): 277–312. doi:10.3366/word.2018.0131.

Levelt, Willem J.M., Ardi Roelofs and Antje S. Meyer. 1999. A theory of lexical access in speech production. *Behavioral and Brain Sciences* 22 (1): 1–38. doi:10.1017/s0140525x99001776.

Levin, Simon A. 1970. Community equilibria and stability, and an extension of the competitive exclusion principle. *The American Naturalist* 104: 412–423. doi:10.1086/282676.

Maiden, Martin. 2005. Morphological autonomy and diachrony. In *Yearbook of morphology 2004*, edited by Geert Booij and Jaap van Marle, 137–175. Dordrecht: Springer.

Marelli, Marco, and Marco Baroni. 2015. Affixation in semantic space: Modeling morpheme meanings with compositional distributional semantics. *Psychological Review* 122 (3): 485–515. doi:10.1037/a0039267.

Matthews, Peter H. 1972. *Inflectional morphology: A theoretical study based on aspects of Latin verb conjugation*. Cambridge: Cambridge University Press.

Nida, Eugene A. 1949. *Morphology: The descriptive analysis of words*. Ann Arbor: University of Michigan Press.

Plag, Ingo, and Laura Winther Balling. 2020. Derivational morphology: An integrative perspective on some fundamental questions. In *Word knowledge and word usage: A cross-disciplinary guide to the mental lexicon*, edited by Vito Pirrelli, Ingo Plag and Wolfgang U. Dressler, 295–335. Berlin: De Gruyter Mouton.

Rueckl, Jay G., and Michal Raveh. 1999. The influence of morphological regularities on the dynamics of a connectionist network. *Brain and Language* 68 (1–2): 110–117. doi:10.1006/brln.1999.2106.

Saussure, Ferdinand de. 1986 [1916]. *Course in general linguistics*. La Salle, IL: Open Court.

Siddiqi, Daniel. 2019. Distributed Morphology. In *The Oxford handbook of morphological theory*, edited by Jenny Audring and Francesca Masini, 143–165. Oxford: Oxford University Press.

Sims, Andrea D. 2015. *Inflectional defectiveness*. Cambridge: Cambridge University Press.

Sims, Andrea D., Adam Ussishkin, Jeff Parker and Samantha Wray. 2022. At the intersection of cognitive processes and linguistic diversity. In *Morphological diversity and linguistic cognition*, edited by Andrea D. Sims, Adam Ussishkin, Jeff Parker and Samantha Wray, 1–28. Cambridge: Cambridge University Press.

Spencer, Andrew. 2013. *Lexical relatedness*. Oxford: Oxford University Press.

Stewart, Thomas W. 2015. *Contemporary morphological theories: A user's guide*. Edinburgh: Edinburgh University Press.

Stump, Gregory T. 2001. *Inflectional morphology: A theory of paradigm structure*. Cambridge: Cambridge University Press.

Stump, Gregory T. 2016. *Inflectional paradigms: Content and form at the syntax–morphology interface*. Cambridge: Cambridge University Press.

Stump, Gregory T., and Raphael A. Finkel. 2013. *Morphological typology: From word to paradigm*. Cambridge: Cambridge University Press.

Zwicky, Arnold M. 1992. Some choices in the theory of morphology. In *Formal grammar: Theory and implementation*, edited by Robert Levine, 327–371. Oxford: Oxford University Press.

3

THE ROLE OF EMBEDDED WORDS AND MORPHEMES IN READING

Elisabeth Beyersmann and Jonathan Grainger

This chapter describes a theoretical framework of complex word reading, as well as a selective empirical review of the morphological processing and visual word recognition literature. We first describe the theoretical foundations of the model and a number of key findings that motivated this approach. The chapter then outlines the backstory by providing a review of the empirical evidence including two lines of reading research. One line of research centres around the investigation of complex (*farmer*) and pseudo-complex words (*corner*) and speaks in favour of a fast-acting segmentation mechanism that decomposes (pseudo)complex words into morphemic subunits (*farm + er; corn + er*) on the basis of superficial morphological structure. The other line of research focuses on the examination of complex nonwords (*farmity*) and provides evidence for a non-morphological mechanism of embedded word activation. Finally, we draw conclusions and outline directions for future research.

The Word and Affix Model of Complex Word Reading

Since the seminal work of Taft and Forster (1975), affixes were thought to be the key to morphological processing (see Rastle & Davis, 2008 for a review), with the idea being that affixes are rapidly "stripped off," which then in turn allows for the isolation and identification of the stem morpheme.[1] Although for many years affix-stripping has provided an influential account for pseudo-morphological segmentation effects (e.g., Aronoff et al., 2016; Kingma, 2013; Longtin & Meunier, 2005; Longtin et al., 2003; Rastle & Davis, 2008; Rastle et al. 2004; Taft, 1981; Taft et al., 1986), the account faces a serious problem: the stripping off of the affix often leaves a word that does not function as a stem. This "garden path" occurs with pseudo-affixed words like "relate" and "corner," which are relatively frequent in languages such as English and French (Baayen, 1993; Colé et al., 1986). Moreover, recent findings have shown that embedded stems can be activated even if accompanied by a non-morphological unit

DOI: 10.4324/9781003159759-3

(e.g., Beyersmann, Casalis et al., 2015; Morris et al., 2011) and that stems appear to represent prominent units in the reading system (Grainger & Beyersmann, 2017), which are easily accessed and acquired early in children's reading development (Beyersmann, Grainger, et al., 2019). This empirical turn has forced a re-evaluation of the affix-stripping approach (i.e., the sequential process of removing the affix and then isolating the stem morpheme). The Word and Affix model implements a similar process, morpho-orthographic full decomposition, but with the parallel operation of a non-morphological process of edge-aligned embedded word activation combined with the morphological process of affix activation. The Word and Affix model, to be described here, is an updated version of the initial Grainger and Beyersmann model (Grainger & Beyersmann, 2017), including a modified and more detailed description of the mechanisms involved in the recognition of complex words.[2] Several recent findings have led us to reconsider certain aspects of our original model. We therefore note that although the updated model is similar to its predecessor, it is not identical.

The Word and Affix model builds on the idea that stems and affixes have a different status in the reading system. As opposed to affixes, the majority of stems are free-standing words that do not require setting up specialized morphological representations. However, a small subset of stems do not exist as free-standing words (i.e., "bound stems" such as *flate* in *deflate* and *inflate*). Given the evidence that bound stems contribute to morphological processing (e.g., Solomyak & Marantz, 2009; Taft, 1994, 2003; Taft & Forster, 1975), we would argue that this arises from the combination of affix activation and the connectivity created by the semantic representations that are shared by the members of the morphological family of bound stems (e.g., *deflate* meaning the opposite of *inflate*).[3]

Under normal reading conditions, affix processing always operates in the presence of a stem, whereas (embedded) word processing does not require the presence of an affix. This is likely one of the reasons why young children quickly learn to identify embedded stems (which are typically also encountered as free-standing words, with the exception of bound stems) early in their reading development (Beyersmann, Grainger et al., 2019; Nation & Cocksey, 2009), whereas the acquisition of a fast-acting affix-processing mechanism takes more time to develop (Beyersmann et al., 2012; Dawson et al., 2018; Schiff et al., 2012). Moreover, while stems can occur in both initial (*pack* in *packing*) and final (*pack* in *unpack*) positions of a letter string and readers are equally good at picking up on embedded stem units at both "edges" of the letter string (e.g., Beyersmann, Cavalli et al., 2016; Crepaldi et al., 2013; Duñabeitia et al., 2009; Heathcote et al., 2018), affixes have clear positional constraints (e.g., Carden, Barreyro, Segui, & Jaichenco, 2019; Crepaldi et al., 2016; Crepaldi et al., 2010; Liu et al., 2014). Therefore, affix processing requires additional constraints that prevent the reading system from activating affixes in the wrong position (e.g., *er* in *error*). Finally, visual word recognition studies have revealed evidence for two distinct stem- and affix-processing mechanisms (see "Morphological Processing" and "Embedded Word Processing" below), thus providing further evidence for the distinct roles of stems[4] and affixes in reading.

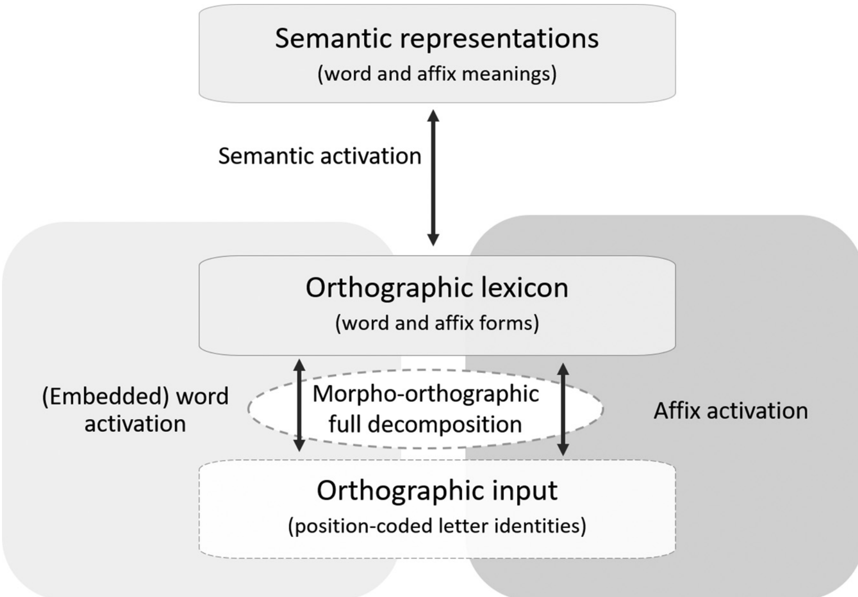

FIGURE 3.1. The "word and affix" model of complex word reading. Orthographic input is mapped onto the orthographic lexicon based on two mechanisms that operate in parallel: (embedded) word activation and affix activation. The principle of "morpho-orthographic full decomposition" operates in the links between the orthographic input (a string of letters) and the entities activated in the orthographic lexicon, by comparing the sum of the letters in the embedded word and the affix with the letters of the input. Representations within the orthographic lexicon are mapped onto a third layer of semantic representations. Connections between layers are bidirectional, thus allowing for bottom-up as well as top-down transfer of information between the three layers.

To account for the outlined differences between stems and affixes, the Word and Affix model implements two different mechanisms within a three-layered reading model (Figure 3.1). During the initial stage of word recognition, orthographic input is mapped onto the orthographic lexicon using two parallel mechanisms: (embedded) word activation (light-grey box, Figure 3.1) and affix activation (dark-grey box, Figure 3.1). The orthographic lexicon contains representations of all word and affix forms that a given reader is familiar with. The active units in the orthographic lexicon are then (i) subjected to a "morpho-orthographic full decomposition" check (dotted box, Figure 3.1), which operates in the links between the orthographic input and the orthographic lexicon; and (ii) mapped onto semantics. Given the bidirectional links between the three processing layers, information can flow both forward and backward. Units in the orthographic lexicon can benefit from semantic feedback if the active constituents are semantically compatible. Below we provide a detailed description of each of the model's features.

Embedded Word Activation

Embedded word activation is a central ingredient of the model. This mechanism achieves a match between the letters of the orthographic input (*f-a-r-m-e-r*) and the orthographic lexicon, including not only those representations that provide an exact match with the entire input string (*farmer*), but also those that are embedded as an edge-aligned orthographic subset (e.g., the *farm* in *farmer*), thus leading to the simultaneous activation of whole words and embedded words (Kuperman et al., 2008; Kuperman et al., 2009). The activation of embedded words is an entirely non-morphological process that extends to words embedded in morphologically simple words (e.g., the *cash* in *cashew*) Embedded words also represent prominent units in the parafoveal processing of complex words (Hyönä et al., 2020). As a result, the orthographic input is mapped in parallel onto not just one single whole-word representation, but several such representations, including embedded words. Moreover, flexibility in letter-position coding (i.e., coarse-grained letter processing; Grainger & Ziegler, 2011) enables the activation of orthographically underspecified stems (e.g., *ador* in *adorable*; McCormick et al., 2008; McCormick et al., 2009) and orthographically similar words. Embedded word activation is influenced by several factors, including (embedded) word length (Beyersmann, Grainger et al. 2019), word frequency (Duñabeitia et al., 2007; Shoolman & Andrews, 2003), morphological family size (Beyersmann & Grainger, 2018), conditional affix probability (Grainger & Beyersmann, 2020), and edge-alignedness (Beyersmann et al. 2018; Grainger & Beyersmann, 2017). Here, we examine the role of each of these factors.[5]

Embedded Word Length

When the orthographic input contains several embedded words (e.g., *far* and *farm* in *farmer*), the model gives preference to the longer embedded unit (*farm*), which is typically the one that forms the morphemic stem of a suffixed word (Beyersmann, Grainger et al., 2019). The longer embedded unit generally also represents the morphemic stem of prefixed words (e.g., the stem of *prepaid* is *paid* and not *aid*). This idea finds empirical support in the results from a word-naming task (Experiment 2 in Beyersmann, Grainger et al., 2019) showing that participants were more likely to name the longer than the shorter embedded word. Embedded word length thus represents one of the factors that determine embedded word activation strength. The model captures this aspect in the connections between layers, with longer embedded words receiving more bottom-up support compared to shorter embedded units.

Embedded Word Frequency

The second factor determining embedded word activation strength is word frequency. The facilitatory effect of word frequency on word recognition—that is, high-frequency words are processed more efficiently than low-frequency words—

has been widely replicated in the reading literature (for a review, see Brysbaert et al., 2017). Crucially, morphologically complex words with high-frequency constituents are recognized faster than words with low-frequency constituents (e.g., Duñabeitia et al., 2007; Hyönä & Pollatsek, 1998; Juhasz, Starr, Inhoff, & Placke, 2003; Shoolman & Andrews, 2003; Taft, 1979). The model captures the word frequency effect and the constituent frequency effect by implementing increasingly heavier weightings on the links between the orthographic input and the orthographic lexicon for items with increasing (embedded) word frequency.

Morphological Family Size

Morphological family size is defined as the number of morphologically complex words in which the word or its stem occurs as a constituent (Schreuder & Baayen, 1997), which can vary substantially across different words. Lexical decisions are faster and more accurate with words with a large compared to a small morphological family (e.g., Bertram, Baayen, & Schreuder, 2000; Boudelaa & Marslen-Wilson, 2011; De Jong, 2002; Juhasz & Berkowitz, 2011; Kuperman, Schreuder, Bertram, & Baayen, 2009; Moscoso del Prado Martín, Bertram, Häikiö, Schreuder, & Baayen, 2003), a finding that has been replicated across several languages (for a review, see Mulder, Dijkstra, Schreuder, & Baayen, 2014). Also, embedded word priming effects are modulated by the morphological family size of the embedded word (Beyersmann & Grainger, 2018), with greater priming for stems with larger families. The model captures this effect in the supra-lexical links between the orthographic lexicon and the semantic representation layer. Words from the same morphological family (e.g., *watery, waterless, waterproof*, etc.) are all connected via a higher-level semantic representation of the stem that they share (*water*). Each time a reader encounters a member of the morphological family (e.g., *watery*), it generates partial activity in the lexical representations of other family members (*waterless, waterproof*, etc.), which are all connected to the semantic representation of *water*. The strength of feedback from this supra-lexical representation of the morphological family to the lexical representations of the family members is determined by the size of the family, such that the larger the family the greater the support provided by the family to each of its members (see Giraudo & Grainger, 2001 for an earlier description of the same mechanisms).

Conditional Affix Probability

Conditional Affix Probability (CAP) represents the likelihood that a morphologically simple word will be accompanied by a (pseudo)affix within all words that contain that word at an edge-aligned position (Grainger & Beyersmann, 2020). CAP is highly correlated with the morphological family size measure, but instead of simply providing an estimate of the number of words that can be formed by adding an affix, it also takes into account the number of words that can be formed by adding a non-affix. CAP is calculated by dividing the cumulative frequency of all words that can be formed by adding a derivational affix (cumulative derived word frequency—CDF) by the cumulative frequency of all words that can be formed by adding a derivational affix (CDF) or a non-affix (cumulative morphologically simple word frequency—CSF): CAP = CDF/(CDF + CSF). Masked priming results from suffixed words[6] show that non-suffixed word priming is significantly modulated by CAP, where embedded words with high CAP produced more priming than those with low CAP (Grainger & Beyersmann, 2020). This modulating effect is not seen with pseudo-suffixed words, suggesting that the presence of a suffix facilitates embedded word activation independently of CAP. This provides important evidence for the complex interplay between stems and affixes, as described in more detail under "Lexical Inhibition" below.

Edge-Alignedness

The model further predicts that priority is given to words embedded at the "edges" of the letter string, based on the idea that the spaces on each side of the letter string act as anchor points for the encoding of letter position (Fischer-Baum et al., 2011). This prediction was tested in a masked priming study by Beyersmann et al. (2018). Significant priming effects were found for edge-aligned embedded constituents (*pimebook-BOOK*), but not for mid-embedded (*pibookme-BOOK*) or outer-embedded constituents (*bopimeok-BOOK*), suggesting that edge-alignedness is a key factor determining the activation of embedded words. Moreover, studies investigating compound words consisting of two edge-aligned embedded constituents show that real compounds (*headache-HEAD*) and pseudo-compounds (*butterfly-BUTTER*) yield comparable priming effects, with both being significantly stronger than priming in the non-compound (*sandwich-SAND*) control condition (Beyersmann, Grainger et al., 2019; Fiorentino & Fund-Reznicek, 2009). Within the Word and Affix model, the word *butterfly* will, for instance, activate the lexical representations of the word itself and the edge-aligned embedded words *butter* and *fly*. Non-compound primes like *sandwich* fail to produce priming, because they do not comply with the principle of morpho-orthographic full decomposition (see below).

Affix Activation

Parallel to the mechanism of (embedded) word activation, the model implements a second affix activation mechanism, which facilitates the mapping of the input letter string onto existing morpho-orthographic form representations in the orthographic lexicon (Lelonkiewicz et al., 2020). Morphological word formation tends to preserve the precise orthographic form of the affix, whereas the orthographic forms of embedded stems can be compromised (e.g., the affix *-able* remains intact in *adorable*; the affix *-er* remains intact in *runner*, etc.). Therefore, the activation of affixes in our model is based on precise letter position decoding (i.e., fine-grained processing; Grainger & Ziegler, 2011), which ensures that affixes are only identified when the letters of the input provide a precise orthographic match. The mechanism is dedicated to activating affix representations (e.g., *-ity*) independently of whether they are attached to a morphemic stem (*farm-ity*) or a non-stem (*falm-ity*), as long as they are edge-aligned and marked in the correct position (string final for suffixes, string initial for prefixes). The model captures this aspect by implementing affix representations that are tagged with position-specific "boundness" markers in the orthographic lexicon (e.g., *_ity, _er, dis_, un_*, etc.). Affix activation works on the basis of a purely structural, semantically independent analysis of the embedded letter sequences (e.g., Beyersmann, Ziegler, et al., 2016; Rastle et al., 2004). As such, even pseudo-complex words like *corner* activate the representation of the pseudo-suffix *-er*.

Morpho-Orthographic Full Decomposition

The initial affix and embedded word-mapping processes lead to the activation of a set of form representations within the orthographic lexicon, which are then subjected to a morpho-orthographic full decomposition check that is triggered whenever all three of the following conditions are satisfied: (1) an edge-aligned embedded word is activated; (2) this embedded word activation is accompanied either by the activation of an affix or another embedded word aligned to the opposite edge;[7] and (3) a word is activated that matches the length of the input. This process examines whether or not the orthographic input can be exhaustively decomposed into morphemes. It operates by comparing the sum of the letters in the embedded word and the affix with the complete set of input letters. If successful (e.g., in the case of C O R N + E R = C O R N E R), it counterbalances inhibition between the whole word *corner* and the embedded word *corn* and thus maintains the level of activation to the embedded word (see Figure 3.2, mid-panel).

Morpho-orthographic full decomposition is also successful if the activated embedded word is orthographically underspecified (e.g., *ador* in *adorable*). That is, the full decomposition check tolerates minor deviations such as the letter E in ADORE not being present at 5th position in the word ADORABLE. A boost in activation of the embedded pseudo-stem does not occur if the letter string is not exhaustively decomposable into morphemes (as in *cashew*), or if the sum of the embedded word and the affix fails to form a real word (*farm + ity = farmity*). The latter failure arises because the process of morpho-orthographic full decomposition requires a whole-word match to the complete input string in order to be initiated. However, the embedded word activation mechanism does function with nonwords, such that "farm" is activated upon presentation of *farmity* or *farmald*.

Lexical Inhibition

The challenge for the reading system is that, more often than not, the orthographic input will activate several lexical representations that are simultaneously active within the orthographic lexicon. For word recognition to be successful, the system has to solve the competition between units by selecting the candidate that reaches the highest activation level within the orthographic lexicon. Interactive activation models (e.g., McClelland & Rumelhart, 1981) implement lateral inhibition between co-active

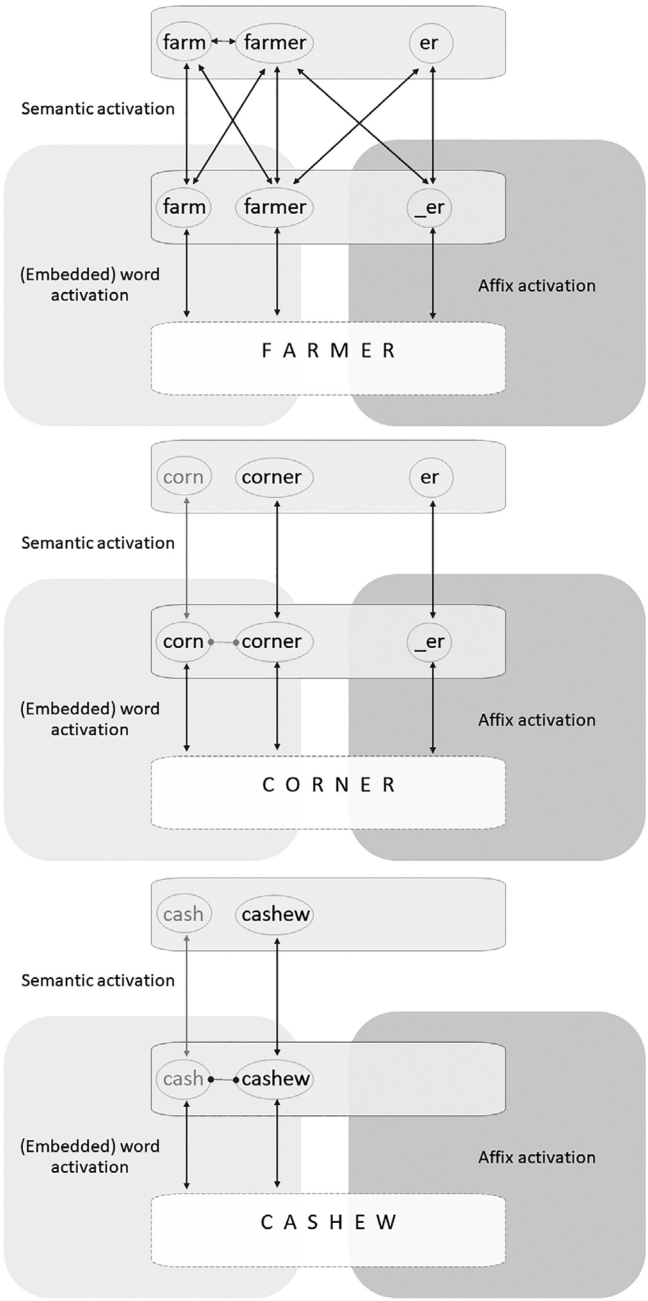

FIGURE 3.2. Detailed description of the model's handling of truly suffixed words (e.g., *farmer*), pseudo-suffixed words (e.g., *corner*), and non-suffixed words (e.g., *cashew*). The success of morpho-orthographic full decomposition with pseudo-suffixed words alleviates the lateral inhibition operating between the whole-word and the embedded word, compared with non-suffixed embedded words.

word units in order to facilitate this process. Our model posits that—besides the many above outlined factors influencing the strength by which embedded words and affixes are activated in the orthographic lexicon—the presence or absence of a transparent morphological relation between units that are simultaneously active in the orthographic lexicon modulates the degree of lateral inhibition (Grainger & Beyersmann, 2017).

Non-suffixed words (*cashew*) and their embedded words (*cash*) are connected via inhibitory links (Figure 3.2, bottom panel). Similarly, in words with a pseudo-morphological structure, the lexical representations of the whole word (*corner*) and the embedded word (*corn*) share lateral inhibitory connections (Figure 3.2, mid-panel). Here, however, the successful application of the morpho-orthographic full decomposition principle leads to a decrease in lexical inhibition (see dimmed inhibitory links between *corn* and *corner* in Figure 3.2). As a result, the lexical node of *corn* is activated more strongly than the lexical node of *cash*, whose activity is reduced due to unmodified lateral inhibition between the two lexical representations. Thus, the presence of a pseudo-suffix tricks the system into believing that the embedding word and the embedded word are compatible whole-word orthographic representations that should be allowed to remain co-active (Grainger & Beyersmann, 2020). In words with a genuine morphological structure, the whole word and the embedded word are unaffected by lateral inhibition and connected via facilitatory top-down links from semantics (Figure 3.2, top panel).[8]

Semantic Activation

The final stage of the complex word reading is the level of semantic representations which are connected to lexical representations via bi-directional excitatory links.[9] Semantic activation can thus flow from the level of the orthographic lexicon to the semantic level and vice versa. Figure 3.2 describes how words with a genuine morphological structure (*farmer*) benefit from the inter-connectivity between the lexical and semantic levels. The lexical node of *farm* is connected to the semantic nodes of *farm* and *farmer*; the lexical node of *farmer* is connected to the semantic nodes of *farm, farmer*, and *-er*; and the lexical node of *-er* is connected the semantic nodes of *farmer* and *-er*. In contrast to *farmer*, words like *corner* and *cashew* do not share semantic interconnectivity with their embedded words (*corn* and *cash*), and the pseudo-suffix *-er* is not semantically linked to the whole word *corner*. The influence of semantic transparency tends to increase as processing of the orthographic input evolves (see "Semantic Influences on Morphological Processing" below). The model explains this finding because of the time required to activate semantic representations and subsequently provide feedback to ongoing word recognition processes.[10]

Morphological Processing

Following the theoretical portrayal of the model, the next two sections will turn to an empirical description of complex word processing. We will begin with a summary of experimental findings that speak in favor of a mechanism that detects affixes during the early stages of reading. Then, we will discuss results that lay the foundation of the model's morpho-orthographic full decomposition principle. The empirical review primarily centers on studies providing insights into the early, automatic stages of visual word recognition, such as those using the masked primed lexical decision paradigm, or neuroimaging techniques with high temporal resolution, including Electroencephalography (EEG) and Magnetoencephalography (MEG). Finally, we will describe evidence for semantic influences on morphological processing, which the model captures in the form of top-down feedback from semantics.

Evidence for Affix Activation

Evidence for affix activation comes from a recent French lexical decision study comparing four different types of nonwords (note that item examples are provided in English), consisting of stem + suffix (*farm* + *ity*), stem + non-suffix (*farm* + *ald*), non-stem + suffix (*falm* + *ity*), and non-stem + non-suffix (*falm* + *ald*) combinations (Beyersmann et al., 2020). The study showed a graded effect with response latencies being the slowest in the stem + suffix condition, average in the stem + non-suffix and non-stem + suffix conditions, and fastest in the non-stem + non-suffix conditions. This pattern suggests that the presence of morphemes increased the string's resemblance to a real word, thus making it harder to reject it as a nonword (for related findings from reading aloud, see Mousikou et al., 2020).

The critical evidence for affix activation consists in the slower response times in the non-stem + suffix condition compared to the non-stem + non-suffix control condition, showing that affixes are activated even if the whole letter string is not exhaustively decomposable (as in *falmity* or *farmald*, see Figure 3.3). Note that an earlier study by Taft et al. (1986) reported similar findings with prefixed nonwords including bound stems (e.g., *dejoice, tejoice, dejouse, rejouse*: where "de" is a prefix in English and "te" is not, and "joice" is a bound stem while "jouse" is not). Prefixed nonwords were more difficult to classify as nonwords than were non-prefixed nonwords (e.g. *dejoice* vs. *tejoice*), and this difference was larger when the bound stem of the nonword was a genuine stem (*joice*) than when it was not (*jouse*). In our model, the affix effect is explained by affix activation (*de-* in *dejoice/dejouse*). The bound-stem effect is explained by the similarity between *dejoice* and *rejoice*, thus making it harder to reject *dejoice* as a nonword.

Evidence for Morpho-Orthographic Processing

The primary evidence for morpho-orthographic processing comes from masked primed lexical decision studies comparing three types of prime-target pairs: truly suffixed (*farmer-FARM*), pseudo-suffixed (*corner-CORN*), and non-suffixed (*cashew-CASH*). Primes are typically presented in lowercase for about 50 ms, and are immediately followed by the uppercase target (Forster & Davis, 1984). Participants are then asked to quickly decide if the target is a real word or a nonword. Primes are presented so briefly that participants are not aware of their existence, yet facilitatory or inhibitory

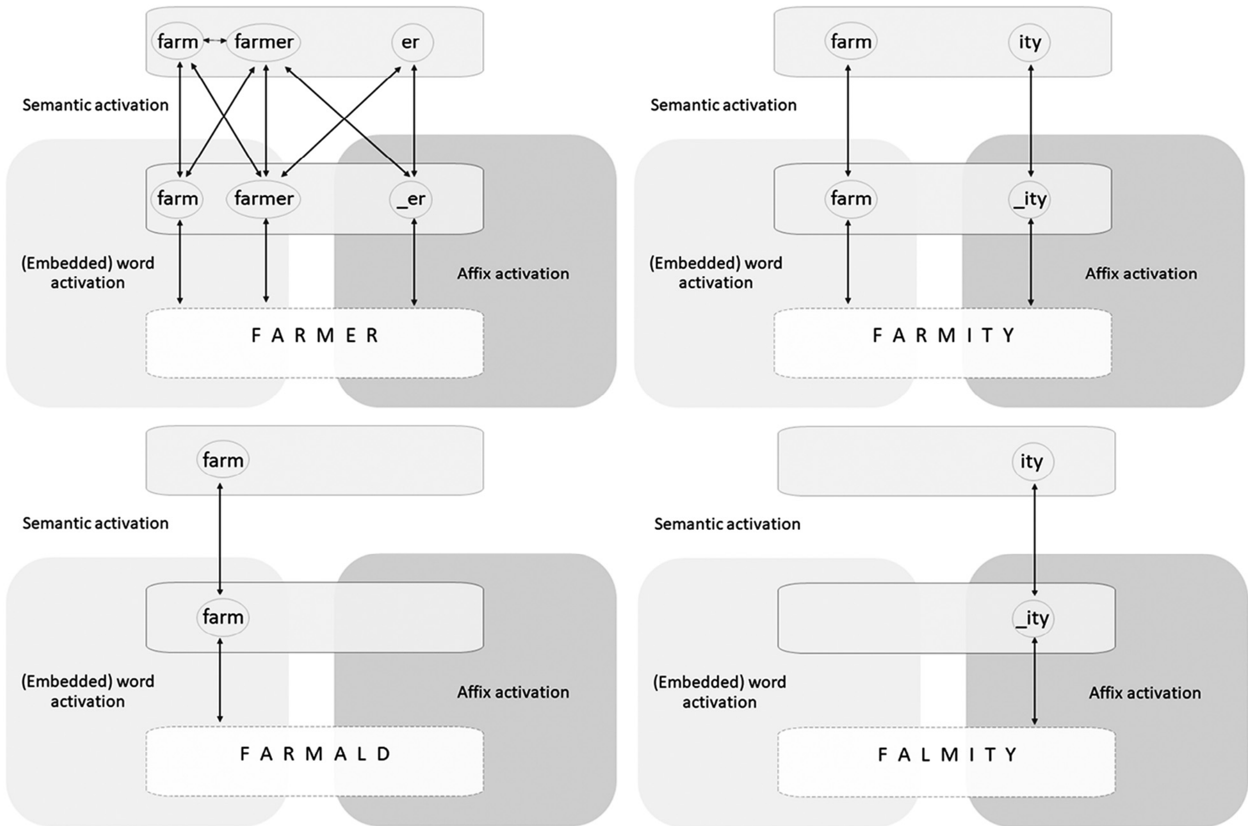

FIGURE 3.3. Detailed description of the model's handling of truly suffixed words (e.g., *farmer*) compared to three types of nonwords: stem + suffix (e.g., *farmity*), stem + non-suffix (e.g., *farmald*), and non-stem + suffix (e.g. *falmity*). The fact that morpho-orthographic full decomposition does not operate with nonword stimuli means that the embedded word "farm" is activated to the same extent by "farmity" and "farmald".

effects on target performance can be measured, thus shedding light on the early, automatic stages of reading. Masked priming results from skilled readers reveal significant priming for truly suffixed and pseudo-suffixed words, but not for non-suffixed words. This early sensitivity for morphological structure in print suggests that skilled readers rapidly decompose complex words into morpho-orthographic units (*farm* + *er, corn* + *er*), independently of whether or not they share a semantic relationship with the whole word (e.g., Amenta & Crepaldi, 2012; Beyersmann, Ziegler et al., 2016; Longtin et al., 2003; Rastle & Davis, 2008; Rastle et al., 2004). The absence of priming in the non-suffixed condition shows that the morpho-orthographic decomposition is not successful in words consisting of an embedded word and a non-morphemic ending (*cashew*, where *ew* is not an affix).

Further evidence for morpho-orthographic processing comes from studies combining masked priming and high-temporal resolution recordings of event-related brain potentials (ERPs; e.g., Beyersmann et al., 2014; Dominguez et al., 2004; Jared et al., 2017; Lavric et al., 2011; Morris et al. 2007; Morris et al. 2008, 2013; Morris et al., 2011; Royle et al., 2012). In the early time windows, ERP responses to true morphological and pseudo-morphological priming are comparable (for converging evidence from MEG, see Lehtonen et al., 2011; Lewis et al., 2011; Solomyak & Marantz, 2009, 2011; but see Jared et al., 2017). In the later time windows, semantic influences on morphological processing are more likely to emerge (see below for more details).

Despite robust evidence for morpho-orthographic decomposition in adults, several masked priming studies with children have shown that morpho-orthographic processing is acquired quite late, not until more advanced stages of reading development (for reviews, see Grainger & Beyersmann, 2017; Rastle, 2018). For instance, Beyersmann et al. (2012) reported significant priming with true morphological primes (*farmer-FARM*) in English-speaking third and fifth graders, but not with pseudo-morphological or non-morphological primes (*corner-CORN* and *cashew-CASH*), suggesting that children in these age groups only decomposed letter strings with a semantically transparent morphological structure. Similarly, Schiff et al. (2012) showed that morpho-orthographic priming did not emerge until high school (but see Quémart et al., 2011). This indicates that morphological processing is primarily guided by semantics during the initial stages of reading acquisition (Stage 1, Figure 3.4).

Semantic Influences on Morphological Processing

Morphemes are defined as the smallest meaningful subunits, but there is debate as to *how early* morphological processing is influenced by semantics (e.g., Cavalli et al., 2016; Feldman et al., 2015; Feldman et al., 2009). Some studies have reported equal magnitudes of priming for truly and pseudo-suffixed words, suggesting that the initial stages of morphological processing are semantically "blind" (e.g., Beyersmann, Ziegler et al., 2016; Longtin et al., 2003; Rastle & Davis, 2008; Rastle et al., 2004). Others have revealed significantly stronger priming with truly

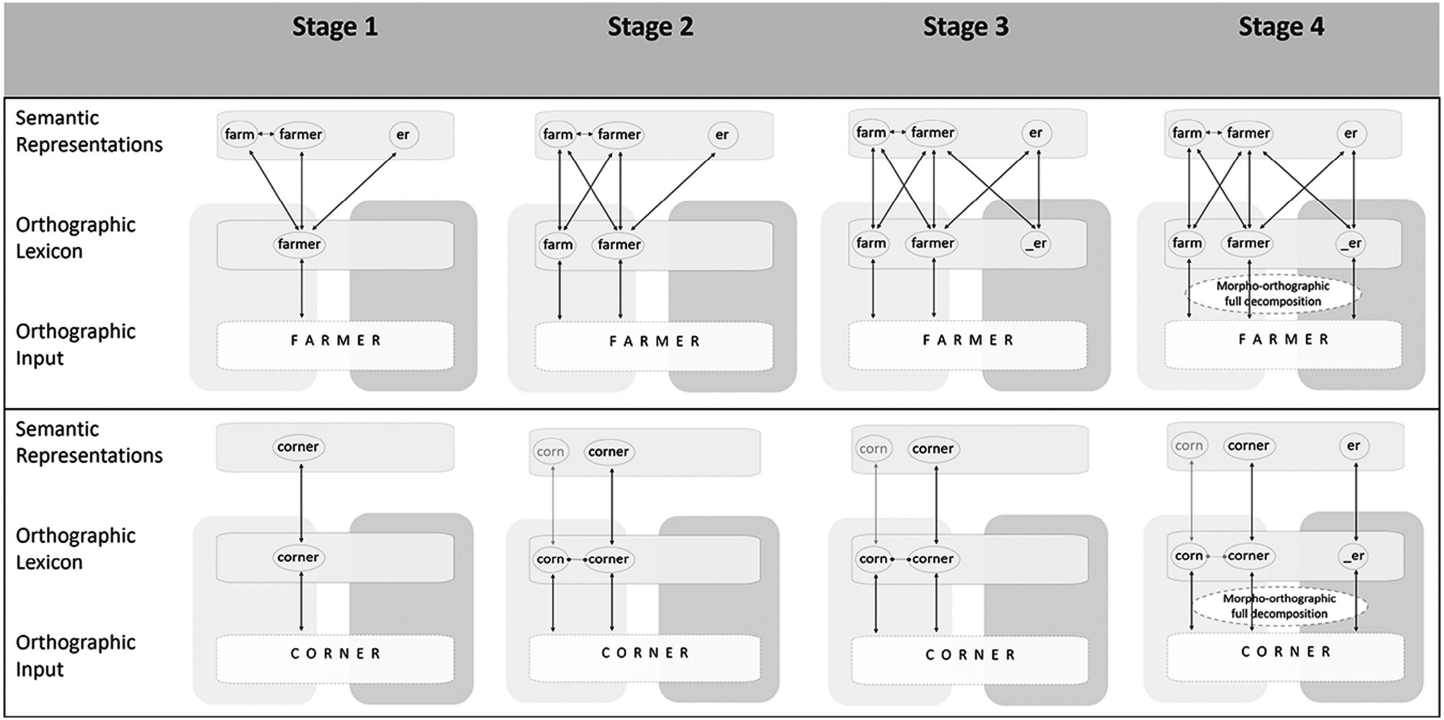

FIGURE 3.4. Four stages of learning to read complex words (updated version of Grainger & Beyersmann, 2017). Stage 1: Acquisition of whole-word orthographic representations that map onto semantic representations. Stage 2: Development of associations between orthographic input and embedded words, including the acquisition of inhibitory links between semantically unrelated lexical representations that are simultaneously active (e.g., between *corn* and *corner*). Stage 3: Acquisition of morpho-orthographic affix representations for semantically transparent morphologically complex words via feedback from semantics. Stage 4: Development of associations between orthographic input and orthographic affix representations, and acquisition of morpho-orthographic full decomposition, leading to a decrease in lateral inhibition between pseudo-suffixed words and their embedded pseudo-stems.

affixed words, suggesting that semantics modulate the initial stages of visual word recognition (e.g., Feldman et al., 2015; Feldman et al., 2009; Jared et al., 2017; Schmidtke et al., 2017). The latter view is consistent with parallel distributed processing theories (e.g., Gonnerman et al., 2007; Plaut & Gonnerman, 2000) according to which the reading system picks up on statistical regularities, such as the consistency with which the letters of a morpheme are mapped onto semantics.

While the debate continues, the general trend shows that semantic influences increase when participants have more time to thoroughly process the prime. For instance, studies using visible primes have revealed stronger priming with true morphological compared to pseudo-morphological primes (e.g., Lavric et al., 2011; Rastle et al., 2000). Moreover, EEG data shows robust neurological priming in the later time windows with truly complex but not pseudo-complex words (e.g., Beyersmann et al., 2014; Lavric et al., 2011; see also Lavric et al., 2012; Morris et al., 2007). Similarly, a range of other experimental methods tapping into slightly later reading stages have provided evidence for semantic influences on morphological processing, including cross-modal priming experiments with auditory primes (e.g., Diependaele et al., 2005; Kielar & Joanisse, 2011; Marslen-Wilson et al., 1994; Meunier & Longtin, 2007), lexical decision studies with complex targets (Marslen-Wilson et al., 2008), and studies using the flanker task (Grainger et al., 2020).

Semantic feedback also explains why in an unprimed lexical task (Beyersmann et al., 2020) complex nonwords (*farmity*) are harder to reject than nonwords containing only one morpheme (*farmald* or *falmity*) or no morpheme (*falmald*). Complex nonwords like *farmity* do not benefit from the principle of morpho-orthographic full decomposition, because the sum of *farm* and *ity* is not a word. Therefore, under masked priming, comparable magnitudes of priming are typically seen for *farmity-FARM* and *farmald-FARM* (e.g., Beyersmann, Casalis et al., 2015; Beyersmann et al., 2014; Heathcote et al., 2018). In unprimed lexical decisions, however, the longer stimulus presentation duration leads to more semantic activation for complex nonwords like *farmity* compared to *farmald* or *falmity*, thus explaining the larger interference effects in this condition (Beyersmann et al., 2020).

Embedded Word Processing

Studies providing evidence for morpho-orthographic processing (e.g., Beyersmann, Ziegler, et al., 2016; Longtin et al., 2003; Rastle et al., 2004) have recently been paralleled by another body of masked priming research providing evidence for an entirely non-morphological process of embedded word activation (e.g., Beyersmann, Casalis et al., 2015; Morris et al., 2011). The critical comparison in the morphological nonword-priming paradigm is between affixed real words (*farmer-FARM*), affixed nonwords (*farmity-FARM*; consisting of a real stem and a real affix), and non-affixed nonwords (*farmald-FARM*; consisting of a real stem followed by a non-morphemic ending). The results from this widely replicated paradigm show that affixed nonwords (*farmity-FARM*) and non-affixed nonwords (*farmald-FARM*) yield comparable magnitudes of priming (e.g., Beyersmann, Casalis et al., 2015; Beyersmann, Cavalli, et al., 2016; Hasenäcker et al., 2016; Heathcote et al., 2018; Morris et al., 2011; Taft et al., 2018), indicating that nonwords produce priming independent of the presence or absence of an affix. Comparable magnitudes of priming are also seen with complex compound nonwords (e.g., *pilebook-BOOK*) and non-compound nonwords (e.g., *pimebook-BOOK*) in line with the idea that embedded word activation is not influenced by the morphological decomposability of the letter string (Beyersmann, Grainger et al., 2019; Beyersmann et al., 2018; Fiorentino et al., 2016).

These findings inspired the development of the Word and Affix model, according to which the input *farmity* is mapped onto the representations of *farm* (via embedded word activation) and *ity* (via affix activation), thus producing significant embedded word priming. The input *farmald* also activates the embedded word *farm*, thus producing equally strong embedded word priming. The magnitude of priming for words embedded in initial and final string position (*subcheap-CHEAP* vs. *cheapize-CHEAP*) is comparable (Beyersmann, Cavalli, et al., 2016; Beyersmann et al., 2018; Crepaldi et al., 2013; Heathcote et al., 2018), but reduced for words embedded in mid position (*pibookme-BOOK*) or outer position (*bopimeok-BOOK*), suggesting that the reading system gives preference to words embedded in edge-aligned string position (Grainger & Beyersmann, 2017).

Results from embedded word priming studies have also been able to shed new light onto how beginning readers process complex words. To examine the nature of embedded word processing in reading development, several recent masked priming studies have applied the complex nonword priming paradigm to a younger population of primary schoolers (Beyersmann, Grainger et al., 2015; Beyersmann et al., 2021; Hasenäcker et al., 2016; Hasenäcker et al., 2020). What is found is that, just like in adults, the size of affixed and non-affixed nonword priming is comparable (*farmity-FARM* vs. *farmald-FARM*), suggesting that children acquire the ability to activate embedded words early in their reading development.

The Word and Affix model captures these developmental aspects in four different stages (Figure 3.4). At Stage 1, children begin to build their orthographic lexicon by acquiring whole-word orthographic representations that map onto semantic representations. Given the wealth of spoken word knowledge that children are already equipped with during the initial reading stages (e.g., Beyersmann et al., 2022; Wegener et al., 2018), the key to Stage 1 is the formation of links between orthographic input and semantics via orthographic whole-word representations. As predicted by Share's (1995) Self-Teaching hypothesis, connections between orthography and semantics are established whenever an unfamiliar orthographic stimulus is successfully phonologically decoded (see also Grainger et al., 2012; Ziegler et al., 2014). Crucially, children already have access to semantic affix representations at Stage 1, based on form-meaning regularities they have been exposed to in their spoken language acquisition (e.g., a *painter* is someone who *paints*, a *teacher* is someone who *teaches*, etc.).

Stage 2 represents the developmental time point by which children begin to pick up on embedded word units. Masked priming results show that embedded word activation is a mechanism that already develops in second grade in children who are not yet fluent readers (Beyersmann, Grainger et al., 2015). As can be seen in Figure 3.4, the development of associations between the orthographic input and embedded words at Stage 2 is independent of whether or not the embedded word and the whole word are semantically related (i.e., both the embedded units *farm* and *corn* are activated in the orthographic lexicon). The aspect that differentiates between truly complex and pseudo-complex words at this stage is that lateral inhibitory links are established between the lexical representations of pseudo-complex words and their pseudo-stems.

At Stage 3, the morphological parsing system reaches a new level of automatization. Via feedback connections from semantics, the reading system begins to establish affix representations in the orthographic lexicon. For instance, the semantic representations of *farmer* and the affix *-er* send excitatory feedback to the lexical level, leading to the addition of morpho-orthographic affix representations.

At Stage 4, associations are then established between orthographic input and orthographic affix representations. It is only at this final stage that affix activation and the associated principle of morpho-orthographic full decomposition are efficiently applied to any given input sting, including words with a pseudo-morphological structure, leading to a decrease in lateral inhibition between pseudo-suffixed words and their embedded pseudo-stems. Our model predicts that at this fully proficient reading stage, whole-word representations remain accessible in the orthographic lexicon (rather than being replaced) alongside the newly established morpho-orthographic form representations. As a result, the recognition of a (pseudo-) complex word can either be achieved on the basis of its orthographic subunits, or via whole-word processing. Reaching Stage 4 requires many years of reading experience, and as prior results have demonstrated this is typically not the case until high school (Beyersmann et al., 2012; Dawson et al., 2018; Dawson et al., 2021; Schiff et al., 2012), although developmental trajectories may differ across different languages (Beyersmann et al., 2021).

A final piece of evidence that makes critical predictions concerning the developmental stages of complex word reading comes from compound priming studies, which show that compound words (*headache-HEAD*) and pseudo-compound words (*butterfly-BUTTER*) yield comparable magnitudes of priming, with both being significantly stronger than priming with non-compound (*sandwich-SAND*) words (Beyersmann, Grainger et al., 2019; Fiorentino & Fund-Reznicek, 2009). This pattern is already evident in children as young as third grade, the age at which children are not yet showing *corner-CORN* priming, providing evidence for a highly automatized form of compound word segmentation in young children (Beyersmann, Grainger et al., 2019). This has important theoretical consequences, suggesting that there is an early use of the morpho-orthographic full decomposition principle, which is only applied to compound words in early stages of reading development, and then also to affixed words at the later stages of reading development.

Conclusions and Future Directions

In this chapter, we have looked back over the past two decades of research examining the recognition of complex words during reading. Results from masked priming point to the distinct roles for stems and affixes in this process, with stems representing freestanding lexical units, encountered early in children's reading development (Beyersmann, Grainger et al., 2019; Beyersmann, et al., 2022), and affixes representing more abstract, specialized morphemic units, which children only acquire later once they already master the basic reading skills (Beyersmann et al., 2012; Schiff et al., 2012). The Word and Affix model provides an alternative to the classic affix-stripping approach developed by Taft and Forster (1975) by implementing the parallel operation of two key mechanisms: embedded word activation and affix activation. The model also implements the principle of morpho-orthographic full decomposition, which works by comparing the sum of the activated edge-aligned embedded word(s) and affix(es), and only takes into consideration the lexical status rather than the morphemic status of the embedded (pseudo-)stem (Grainger & Beyersmann, 2020).

Challenges for future research include the role of individual and cross-linguistic differences in morphological processing at different stages of reading development. Morphological priming effects are modulated by individual differences in language proficiency, suggesting that not all readers benefit from morphological processing to the same extent (e.g., Andrews & Lo, 2013; Beyersmann, Casalis et al., 2015; Beyersmann, Grainger et al., 2015; Hasenäcker et al., 2020), but it is not clear what skills exactly enhance the ability to identify morphological structure. Tests of individual differences vary widely between studies, ranging from reading fluency, reading comprehension, spelling proficiency, vocabulary knowledge, and morphological awareness to other non-linguistic measurements. For instance, adults with higher levels of reading fluency and spelling proficiency are more expert in activating embedded words than less proficient participants (Beyersmann, Casalis et al., 2015), and participants with better vocabulary than spelling ability show greater semantic transparency effects than participants with better spelling than vocabulary skills (Andrews & Lo, 2013). What further complicates the picture is that morphological processing is also not uniform across different languages (e.g., Juola, 2008; Kettunen, 2014; Sadeniemi et al., 2008), showing that readers of different languages benefit from morphological processing in different ways (Beyersmann et al., 2020; Frost, 2009; Mousikou et al., 2020; Beyersmann, et al., 2021). Future research will need to carefully tease apart individual proficiency differences within languages, not only to gain a broader, language-universal perspective of complex word reading, but also to inform language-specific teaching programs involving morphological instruction (Bowers & Bowers, 2018).

The Word and Affix model clearly dissociates (embedded) word activation, affix activation and morpho-orthographic full decomposition as three distinct mechanisms that are motivated by a complex set of psycholinguistic data. If it is true that these mechanisms are clearly distinguishable, we would expect to see differences in the neurobiological underpinnings of embedded word and affix processing. What is needed now is a neurocognitive investigation aimed at understanding how these three specific processes are implemented in the literate brain.

Notes

1 "Affix-stripping" and "morpho-orthographic processing" have often been synonymously used to describe the process of decomposing letter strings into morphemic subunits, independently of semantics. Morpho-orthographic processing is based on the same general idea that morphological decomposition only applies in the presence of an affix (i.e., decomposition of *corn* + *er*, but not *cashew*).

2 Interested readers are referred to Grainger and Beyersmann (2017) for more details on the empirical findings that motivated the key components of the original model.

3 See Taft (this volume) for an alternative account of the processing of bound stems.

4 We use the term "stem" to signify the specific status of stems as embedded words under the principle of full decomposition. That is, the stem is the embedded word that combines with an affix to describe the complete stimulus.

5 We note that the here reported list of factors is not necessarily exhaustive. Our focus is on factors that have been explicitly found to influence embedded word processing.

6 To this date, CAP has only been tested with suffixed words, but not prefixed words.

7 Here we focus on the case of affixed-derived words, but the same mechanisms are thought to operate for compound words.

8 The influence of semantic transparency on morphological processing is difficult to detect in a task like masked priming, not only because primes are presented so briefly that there is not enough time for semantic processing to have an impact, but also because the prime and the target are presented in the same spatial location. Results from the Flanker Paradigm, on the other hand, show that when complex words and their embedded words are presented side-by-side (e.g., *farm farmer farm*) the competition for the same spatial location is removed, and significantly stronger flanker effects are observed for semantically transparent complex words compared to pseudo-complex and non-complex words (Grainger et al., 2020).

9 Given the model's focus on the initial stages of complex word recognition, semantics represents the highest form of representation in this context. Although beyond the scope of the current work, we would suggest that semantic features, as exemplified in the semantic representation of derivational affixes, are the key ingredient of this level of representation. However, in order to keep things simple, we describe the operation of semantics at the word level using localist terminology.

10 As opposed to earlier models of complex word recognition (e.g., Diependaele et al, 2009; Grainger & Beyersmann, 2017), the current model does not implement a mechanism of "morpho-semantic decomposition," which was previously used to account for semantic transparency effects in complex word recognition.

References

Amenta, S., & Crepaldi, D. (2012). Morphological processing as we know it: An analytical review of morphological effects in visual word identification. *Frontiers in Psychology*, 3, 1–12. doi:10.3389/fpsyg.2012.00232.

Andrews, S., & Lo, S. (2013). Is morphological priming stronger for transparent than opaque words? It depends on individual differences in spelling and vocabulary. *Journal of Memory & Language*, 68(3), 279–296. doi:10.1016/j.jml.2012.12.001.

Aronoff, M., Berg, K., & Heyer, V. (2016). Some implications of English spelling for morphological processing. *The Mental Lexicon*, 11 (2), 164–185. doi:10.1075/ml.11.2.01aro.

Baayen, H. (1993). On frequency, transparency and productivity. In G. E. Booij & J. van Marle (Eds.), *Yearbook of Morphology 1992* (pp. 181–208). Dordrecht: Springer Netherlands.

Bertram, R., Baayen, R. H., & Schreuder, R. (2000). Effects of family size for complex words. *Journal of Memory & Language*, 42(3), 390–405. doi:10.1006/jmla.1999.2681.

Beyersmann, E., Castles, A., & Coltheart, M. (2012). Morphological processing during visual word recognition in developing readers: Evidence from masked priming. *The Quarterly Journal of Experimental Psychology*, 65(7), 1306–1326. doi:10.1080/17470218.2012.656661.

Beyersmann, E., Casalis, S., Ziegler, J. C., & Grainger, J. (2015). Language proficiency and morpho-orthographic segmentation. *Psychonomic Bulletin & Review*, 22, 1054–1061. doi:10.3758/s13423-014-0752-9.

Beyersmann, E., Cavalli, E., Casalis, S., & Colé, P. (2016). Embedded stem priming effects in prefixed and suffixed pseudowords. *Scientific Studies of Reading*, 20(3), 220–230. doi:10.1080/10888438.2016.1140769.

Beyersmann, E., & Grainger, J. (2018). Support from the morphological family when unembedding the stem. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 44(1), 135–142.

Beyersmann, E., Grainger, J., Casalis, S., & Ziegler, J. C. (2015). Effects of reading proficiency on embedded stem priming in primary school children. *Journal of Experimental Child Psychology*, 139, 115–126.

Beyersmann, E., Grainger, J., & Castles, A. (2019). Embedded stems as a bootstrapping mechanism for morphological parsing during reading development. *Journal of Experimental Child Psychology*, 182, 196–210. doi:10.1016/j.jecp.2019.01.010.

Beyersmann, E., Grainger, J., & Taft, M. (2019). Evidence for embedded word length effects in complex nonwords. *Language, Cognition and Neuroscience*, 1–11. doi:10.1080/23273798.2019.1659989.

Beyersmann, E., Iakimova, G., Ziegler, J. C., & Colé, P. (2014). Semantic processing during morphological priming: An ERP study. *Brain Research*, 1579, 45–55. doi:10.1016/j.brainres.2014.07.010.

Beyersmann, E., Kezilas, Y., Coltheart, M., Castles, A., Ziegler, J. C., Taft, M., & Grainger, J. (2018). Taking the book from the bookshelf: Masked constituent priming effects in compound words and nonwords. *Journal of Cognition*, 1(1), 1–10.

Beyersmann, E., Mousikou, P., Javourey-Drevet, L., Schroeder, S., Ziegler, J. C., & Grainger, J. (2020). Morphological processing across modalities and languages. *Scientific Studies of Reading*, 24(6), 500–519. doi:10.1080/10888438.2020.1730847.

Beyersmann, E., Mousikou, P., Schroeder, S., Javourey-Drevet, L., Ziegler, J. C., & Grainger, J. (2021). The dynamics of morphological processing in developing readers: A cross-linguistic masked priming study. *Journal of Experimental Child Psychology*, 208, 105140. doi:10.1016/j.jecp.2021.105140.

Beyersmann, E., Ziegler, J. C., Castles, A., Coltheart, M., Kezilas, Y., & Grainger, J. (2016). Morpho-orthographic segmentation without semantics. *Psychonomic Bulletin & Review*, 23, 533–539. doi:10.3758/s13423-015-0927-z.

Boudelaa, S., & Marslen-Wilson, W. D. (2011). Productivity and priming: Morphemic decomposition in Arabic. *Language and Cognitive Processes*, 26(4–6), 624–652. doi:10.1080/01690965.2010.521022.

Bowers, J. S., & Bowers, P. N. (2018). Progress in reading instruction requires a better understanding of the English spelling system. *Current Directions in Psychological Science*, 27(6), 407–412. doi:10.1177/0963721418773749.

Brysbaert, M., Mandera, P., & Keuleers, E. (2017). The word frequency effect in word processing: An updated review. *Current Directions in Psychological Science*, 27(1), 45–50. doi:10.1177/0963721417727521.

Carden, J. R., Barreyro, J. P., Segui, J., & Jaichenco, V. (2019). The fundamental role of position in affix identity. *The Mental Lexicon*, 14(3), 357–380. doi:10.1075/ml.19009.car.

Cavalli, E., Cole, P., Badier, J. M., Zielinski, C., Chanoine, V., & Ziegler, J. C. (2016). Spatiotemporal dynamics of morphological processing in visual word recognition. *Journal of Cognitive Neuroscience*, 28(8), 1228–1242. doi:10.1162/jocn_a_00959.

Colé, P., Beauvillain, C., Pavard, B., & Segui, J. (1986). Organisation morphologique et acces au lexique. *L'Année Psychologique* 86 (3), 349–365. doi:10.3406/psy.1986.29154.

Crepaldi, D., Hemsworth, L., Davis, C. J., & Rastle, K. (2016). Masked suffix priming and morpheme positional constraints. *Quarterly Journal of Experimental Psychology*, 69(1), 113–128. doi:10.1080/17470218.2015.1027713.

Crepaldi, D., Rastle, K., & Davis, C. J. (2010). Morphemes in their place: Evidence for position-specific identification of suffixed. *Memory and Cognition*, 38(3): 312–321. doi:10.3758/MC.38.3.312.

Crepaldi, D., Rastle, K., Davis, C. J., & Lupker, S. J. (2013). Seeing stems everywhere: Position-independent identification of stem morphemes. *Journal of Experimental Psychology: Human Perception and Performance*, 39(2), 510–525. doi:10.1037/a0029713.

Dawson, N., Rastle, K., & Ricketts, J. (2018). Morphological effects in visual word recognition: Children, adolecents, and adults. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 44(4), 645–654. doi:10.1037/xlm0000485.

Dawson, N., Rastle, K., & Ricketts, J. (2021). Finding the man amongst many: A developmental perspective on mechanisms of morphological decomposition. *Cognition*, 211, 104605. doi:10.1016/j.cognition.2021.104605.

De Jong, N. H. (2002). Morphological families in the mental lexicon. In *MPI series in psycholinguistics*. Nijmegen, The Netherlands: Max Planck Institute for Psycholinguistics.

Diependaele, K., Sandra, D., & Grainger, J. (2005). Masked cross-modal morphological priming: Unravelling morpho-orthographic and morpho-semantic influences in early word recognition. *Language and Cognitive Processes*, 20(1–2), 75–114. doi:10.1080/01690960444000197.

Diependaele, K., Sandra, D., & Grainger, J. (2009). Semantic transparency and masked morphological priming: The case of prefixed words. *Memory & Cognition*, 37, 895–908.

Dominguez, A., De Vega, M., & Barber, H. (2004). Event-related brain potentials elicited by morphological, homographic, orthographic, and semantic priming. *Journal of Cognitive Neuroscience*, 16 (4), 598–608. doi:10.1162/089892904323057326.

Duñabeitia, J. A., Laka, I., Perea, M., & Carreiras, M. (2009). Is Milkman a superhero like Batman? Constituent morphological priming in compound words. *European Journal of Cognitive Psychology*, 21(4), 615–640. doi:10.1080/09541440802079835.

Duñabeitia, J. A., Perea, M., & Carreiras, M. (2007). The role of the frequency of constituents in compound words: Evidence from Basque and Spanish. *Psychonomic Bulletin & Review*, 14(6), 1171–1176. doi:10.3758/BF03193108.

Feldman, L. B., Milin, P., Cho, K. W., Moscoso Del Prado Martin, F., & O'Connor, P. A. (2015). Must analysis of meaning follow analysis of form? A time course analysis. *Frontiers in Human Neuroscience*, 9, 1–19. doi:10.3389/fnhum.2015.00111.

Feldman, L. B., O'Connor, P. A., & Moscoso del Prado Martin, F. (2009). Early morphological processing is morpho-semantic and not simply morpho-orthographic: A violation of form-then-meaning accounts of word recognition. *Psychonomic Bulletin & Review*, 16(4), 684–691. doi:10.3758/PBR.16.4.684.

Fiorentino, R., & Fund-Reznicek, E. (2009). Masked morphological priming of compound constituents. *The Mental Lexicon*, 4(2), 159–193. doi:10.1075/ml.4.2.01fio.

Fiorentino, R., Politzer-Ahles, S., Pak, N. S., Martínez-García, M. T., & Coughlin, C. (2016). Dissociating morphological and form priming with novel complex word primes:

Evidence from masked priming, overt priming, and event-related potentials. *The Mental Lexicon*, 10(3), 413–434. doi:10.1075/ml.10.3.05fio.

Fischer-Baum, S., Charny, J., & McCloskey, M. (2011). Both-edges representation of letter position in reading. *Psychonomic Bulletin & Review*, 18(6), 1083–1089. doi:10.3758/s13423-011-0160-3.

Forster, K. I., & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 10(4), 680–698. doi:10.1037/0278-7393.10.4.680.

Frost, R. (2009). Reading in Hebrew vs. reading in English: Is there a qualitative difference? In K. Pugh & P. McCradle (Eds.), *How Children Learn To Read: Current Issues and New Directions in the Integration of Cognition, Neurobiology and Genetics of Reading and Dyslexia Research and Practice* (pp. 235–254). New York: Psychology Press.

Giraudo, H., & Grainger, J. (2001). Priming complex words: Evidence for supralexical representation of morphology. *Psychonomic Bulletin & Review*, 8(1), 127–131. doi:10.3758/bf03196148.

Gonnerman, L. M., Seidenberg, M. S., & Andersen, E. S. (2007). Graded semantic and phonological similarity effects in priming: Evidence for a distributed connectionist approach to morphology. *Journal of Experimental Psychology: General*, 136(2), 323–345. doi:10.1037/0096-3445.136.2.323.

Grainger, J., & Beyersmann, E. (2017). Edge-aligned embedded word activation initiates morpho-orthographic segmentation. In B. H. Ross (Ed.), *The Psychology of Learning and Motivation* (Vol. 67, pp. 285–317). San Diego: Elsevier Academic Press.

Grainger, J., & Beyersmann, E. (2020). Effects of lexicality and pseudo-morphological complexity on embedded word priming. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 47(3), 518–531. doi:10.1037/xlm0000878.

Grainger, J., Lété, B., Bertand, D., Dufau, S., & Ziegler, J. C. (2012). Evidence for multiple routes in learning to read. *Cognition*, 123(2), 280–292. doi:10.1016/j.cognition.2012.01.003.

Grainger, J., Snell, J., & Beyersmann, E. (2020). Morphological processing in the flankers task. *Language, Cognition and Neuroscience*, 36(3), 288–295. doi:10.1080/23273798.2020.1810292.

Grainger, J., & Ziegler, J. C. (2011). A dual-route approach to orthographic processing. *Frontiers in Psychology*, 2(45). doi:10.3389/fpsyg.2011.00054.

Hasenäcker, J., Beyersmann, E., & Schroeder, S. (2016). Masked morphological priming in German-speaking adults and children: Evidence from response time distributions. *Frontiers in Psychology*, 7, 1–11. doi:10.3389/fpsyg.2016.00929.

Hasenäcker, J., Beyersmann, E., & Schroeder, S. (2020). Morphological priming in children: Disentangling the effects of school-grade and reading skill. *Scientific Studies of Reading*, 24 (6), 484–499. doi:10.1080/10888438.2020.1729768.

Heathcote, L., Nation, K., Castles, A., & Beyersmann, E. (2018). Do "blacheap" and "subcheap" both prime "cheap"? An investigation of morphemic status and position in early visual word processing. *Quarterly Journal of Experimental Psychology*, 71(8), 1645–1654. doi:10.1080/17470218.2017.1362704.

Hyönä, J., Heikkila, T. T., Vainio, S., & Kliegl, R. (2020). Parafoveal access to word stem during reading: An eye movement study. *Cognition*, 208, 104547. doi:10.1016/j.cognition.2020.104547.

Hyönä, J., & Pollatsek, A. (1998). Reading Finnish compound words: Eye fixations are affected by component morphemes. *Journal of Experimental Psychology: Human Perception & Performance*, 24(6), 1612–1627. doi:10.1037//0096-1523.24.6.1612.

Jared, D., Jouravlev, O., & Joanisse, M. F. (2017). The effect of semantic transparency on the processing of morphologically derived words: Evidence from decision latencies and event-related potentials. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 43(3), 422–450. doi:10.1037/xlm0000316.

Juhasz, B., & Berkowitz, R. N. (2011). Effects of morphological families on English compound word recognition: A multitask investigation. *Language and Cognitive Processes*, 26(4–6), 653–682. doi:10.1080/01690965.2010.498668.

Juhasz, B., Starr, M. S., Inhoff, A. W., & Placke, L. (2003). The effects of morphology on the processing of compound words: Evidence from naming, lexical decisions and eye fixations. *British Journal of Psychology*, 94(2), 223–244. doi:10.1348/000712603321661903.

Juola, P. (2008). Assessing linguistic complexity. In M. Miestamo, K. Sinnemäki, & F. Karlsson (Eds.), *Language Complexity: Typology, Contact, Change* (pp. 89–108). Amsterdam: John Benjamins Publishing Company.

Kettunen, K. (2014). Can Type-Token Ratio be used to show morphological complexity of languages? *Journal of Quantitative Linguistics*, 21(3), 223–245. doi:10.1080/09296174.2014.911506.

Kielar, A., & Joanisse, M. F. (2011). The role of semantic and phonological factors in word recognition: An ERP cross-modal priming study of derivational morphology. *Neuropsychologia*, 49(2), 161–177. doi:10.1016/j.neuropsychologia.2010.11.027.

Kingma, B. (2013). *An interactive-activation model of affix stripping*. Unpublished master's thesis. University of Groningen. https://drive.google.com/file/d/1sPY2flK2aPgliIm r5VrSNC337rjrH7eh/view?usp=sharing.

Kuperman, V., Bertram, R., & Baayen, R. H. (2008). Morphological dynamics in compound processing. *Language & Cognitive Processes*, 23(7–8), 1089–1132. doi:10.1080/01690960802193688.

Kuperman, V., Schreuder, R., Bertram, R., & Baayen, R. H. (2009). Reading polymorphemic Dutch compounds: Toward a multiple route model of lexical processing. *Journal of Experimental Psychology: Human Perception & Performance*, 35(3), 876–895. doi:10.1037/a0013484.

Lavric, A., Elchlepp, H., & Rastle, K. (2012). Tracking hierarchical processing in morphological decomposition with brain potentials. *Journal of Experimental Psychology: Human Perception and Performance*, 38(4), 811–816. doi:10.1037/a0028960.

Lavric, A., Rastle, K., & Clapp, A. (2011). What do fully visible primes and brain potentials reveal about morphological processing? *Psychophysiology*, 48(5), 676–686. doi:10.1111/j.1469-8986.2010.01125.x.

Lehtonen, M., Monahan, P. J., & Poeppel, D. (2011). Evidence for early morphological decomposition: Combining masked priming with magnetoencephalography. *Journal of Cognitive Neuroscience*, 23(11), 3366–3379. doi:10.1162/jocn_a_00035.

Lelonkiewicz, J. R., Ktori, M., & Crepaldi, D. (2020). Morphemes as letter chunks: Discovering affixes through visual regularities. *Journal of Memory and Language*, 115. doi:10.1016/j.jml.2020.104152.

Lewis, G., Solomyak, O., & Marantz, A. (2011). The neural basis of obligatory decomposition of suffixed words. *Brain and Language*, 118(3), 118–127. doi:10.1016/j.bandl.2011.04.004.

Liu, D., Chung, K. K. H., Zhang, Y., & Lu, Z. (2014). Sensitivity to the positional information of morphemes inside Chinese compound words and its relationship with word reading. *Reading and Writing*, 27(3), 431–450. doi:10.1007/s11145-013-9451-6.

Longtin, C. M., & Meunier, F. (2005). Morphological decomposition in early visual word processing. *Journal of Memory and Language*, 53 (1), 26–41. doi:10.1016/j.jml.2005.02.008.

Longtin, C. M., Segui, J., & Hallé, P. A. (2003). Morphological priming without morphological relationship. *Language and Cognitive Processes*, 18 (3), 313–334. doi:10.1080/01690960244000036.

Marslen-Wilson, W., Bozic, M., & Randall, B. (2008). Early decomposition in visual word recognition: Dissociating morphology, form, and meaning. *Language & Cognitive Processes*, 23(3), 394–421. doi:10.1080/01690960701588004.

Marslen-Wilson, W., Tyler, L., Waksler, R., & Older, L. (1994). Morphology and meaning in the English mental lexicon. *Psychological Review*, 101(1), 3–33. doi:10.1037/0033-295X.101.1.3.

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context Effects in letter perception: Part 1. An account of basic findings. *Psychological Review*, 88 (5), 375–407. doi:10.1037/0033-295X.88.5.375.

McCormick, S. F., Rastle, K., & Davis, M. H. (2008). Is there a 'fete' in 'fetish'? Effects of orthographic opacity on morpho-orthographic segmentation in visual word recognition. *Journal of Memory and Language*, 58(2), 307–326. doi:10.1016/j.jml.2007.05.006.

McCormick, S. F., Rastle, K., & Davis, M. H. (2009). Adore-able not adorable? Orthographic underspecification studied with masked repetition priming. *European Journal of Cognitive Psychology*, 21(6), 813–836. doi:10.1080/09541440802366919.

Meunier, F., & Longtin, C. M. (2007). Morphological decomposition and semantic integration in word processing. *Journal of Memory and Language*, 56(4), 457–471. doi:10.1016/j.jml.2006.11.005.

Morris, J., Frank, T., Grainger, J., & Holcomb, P. J. (2007). Semantic transparency and masked morphological priming: An ERP investigation. *Psychophysiology*, 44(4), 506–521. doi:10.1111/j.1469-8986.2007.00538.x.

Morris, J., Grainger, J., & Holcomb, P. J. (2008). An electrophysiological investigation of early effects of masked morphological priming. *Language and Cognitive Processes*, 23(7–8), 1021–1056. doi:10.1080/01690960802299386.

Morris, J., Grainger, J., & Holcomb, P. J. (2013). Tracking the consequences of morpho-orthographic decomposition using ERPs. *Brain Research*, 1529, 92–104. doi:10.1016/j.brainres.2013.07.016.

Morris, J., Porter, J. H., Grainger, J., & Holcomb, P. J. (2011). Effects of lexical status and morphological complexity in masked priming: An ERP study. *Language and Cognitive Processes*, 26 (4–6), 558–599. doi:10.1080/01690965.2010.495482.

Moscoso del Prado Martín, F., Bertram, R., Häikiö, T., Schreuder, R., & Baayen, R. H. (2003). Morphological family size in a morphologically rich language: The case of Finnish compared to Dutch and Hebrew. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 30(6), 1271–1278. doi:10.1037/0278-7393.30.6.127.

Mousikou, P., Beyersmann, E., Ktori, M., Javourey, L., Crepaldi, D., Ziegler, J. C., Grainger, J., & Schroeder, S. (2020). Orthographic consistency influences morphological processing in reading aloud: Evidence from a cross-linguistic study. *Developmental Science*, 23(6), 1–19. doi:10.1111/desc.12952.

Mulder, K., Dijkstra, T., Schreuder, R., & Baayen, H. (2014). Effects of primary and secondary morphological family size in monolingual and bilingual word processing. *Journal of Memory and Language*, 72, 59–84. doi:10.1016/j.jml.2013.12.004.

Nation, K., & Cocksey, J. (2009). Beginning readers activate semantics from sub-word orthography. *Cognition*, 110 (2), 273–278. doi:10.1016/j.cognition.2008.11.004.

Plaut, D. C., & Gonnerman, L. M. (2000). Are non-semantic morphological effects incompatible with a distributed connectionist approach to lexical processing? *Language and Cognitive Processes*, 15(4–5), 445–485. doi:10.1080/01690960050119661.

Quémart, P., Casalis, S., & Colé, P. (2011). The role of form and meaning in the processing of written morphology: A priming study in French developing readers. *Journal of Experimental Child Psychology*, 109(4), 478–496. doi:10.1016/j.jecp.2011.02.008.

Rastle, K. (2018). The place of morphology in learning to read in English. *Cortex*, 116, 45–54. doi:10.1016/j.cortex.2018.02.008.

Rastle, K., & Davis, M. H. (2008). Morphological decomposition based on the analysis of orthography. *Language & Cognitive Processes*, 23 (7–8), 942–971. doi:10.1080/01690960802069730.

Rastle, K., Davis, M. H., Marslen-Wilson, W., & Tyler, L. K. (2000). Morphological and semantic effects in visual word recognition: A time-course study. *Language and Cognitive Processes*, 15(4–5),507–537. doi:10.1080/01690960050119689.

Rastle, K., Davis, M. H., & New, B. (2004). The broth in my brother's brothel: Morpho-orthographic segmentation in visual word recognition. *Psychonomic Bulletin & Review*, 11, 1090–1098. doi:10.3758/BF03196742.

Royle, P., Drury, J. E., Bourguignon, N., & Steinhauer, K. (2012). The temporal dynamics of inflected word recognition: a masked ERP priming study of French verbs. *Neuropsychologia*, 50(14), 3542–3553. doi:10.1016/j.neuropsychologia.2012.09.007.

Sadeniemi, M., Kettunen, K., Lindh-Knuutila, T., & Honkela, T. (2008). Complexity of European Union languages: A comparative approach. *Journal of Quantitative Linguistics*, 15 (2), 185–211. doi:10.1080/09296170801961843.

Schiff, R., Raveh, M., & Fighel, A. (2012). The development of the Hebrew mental lexicon: When morphological representations become devoid of their meaning. *Scientific Studies of Reading*, 16 (5), 383–403. doi:10.1080/10888438.2011.571327.

Schmidtke, D., Matsuki, K., & Kuperman, V. (2017). Surviving blind decomposition: A distributional analysis of the time-course of complex word recognition. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 43(11), 1793–1820. doi:10.1037/xlm0000411.

Schreuder, R., & Baayen, R. H. (1997). How complex simplex words can be. *Journal of Memory & Language*, 37(1), 118–139. doi:10.1006/jmla.1997.2510.

Share, D. L. (1995). Phonological recoding and self-teaching: Sine qua non of reading acquisition. *Cognition*, 55(2), 151–218. doi:10.1016/0010-0277(94)00645-2.

Shoolman, N., & Andrews, S. (2003). Racehorses, reindeer, and sparrows: Using masked priming to investigate morphological influences on compound word identification. In S Kinoshita & S. J. Lupker (Eds.), *Masked priming: The state of the art* (pp. 241–278). New York: Psychology Press.

Solomyak, O., & Marantz, A. (2009). Evidence for early morphological decomposition in visual word recognition. *Journal of Cognitive Neuroscience*, 22(9), 2042–2057. doi:10.1162/jocn.2009.21296.

Solomyak, O., & Marantz, A. (2011). The neural basis of obligatory decomposition of suffixed words. *Language*, 118(3), 118–127. doi:10.1016/j.bandl.2011.04.004.

Taft, M. (1979). Recognition of affixed words and the word frequency effect. *Memory & Cognition*, 7(4), 263–272. doi:10.3758/BF03197599.

Taft, M. (1981). Prefix stripping revisited. *Journal of Verbal Learning and Verbal Behavior*, 20 (3), 289–297. doi:10.1016/S0022-5371(81)90439-4.

Taft, M. (1994). Interactive-Activation as a framework for understanding morphological processing. *Language and Cognitive Processes*, 9 (3), 271–294. doi:10.1080/01690969408402120.

Taft, M. (2003). Morphological representation as a correlation between form and meaning. In E. Assink & D. Sandra (Eds.), *Reading complex words* (pp. 113–137). Amsterdam: Kluwer.

Taft, M., & Forster, K. I. (1975). Lexical storage and retrieval of prefixed words. *Journal of Verbal Learning and Verbal Behavior*, 14 (6), 638–647. doi:10.1016/S0022-5371(75)80051-X.

Taft, M., Hambly, G., & Kinoshita, S. (1986). Visual and auditory recognition of prefixed words. *The Quarterly Journal of Experimental Psychology*, 38 (3), 351–366. doi:10.1080/14640748608401603.

Taft, M., Li, S., & Beyersmann, E. (2018). What cross-morphemic letter transposition in derived nonwords tells us about lexical processing. *Journal of Cognition*, 1(1), 36. doi:10.5334/joc.39.

Ziegler, J. C., Perry, C., & Zorzi, M. (2014). Modelling reading development through phonological decoding and self-teaching: implications for dyslexia. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 369(1634). doi:10.1098/rstb.2012.0397.

4

MORPHOLOGICAL PROCESSING IN SPOKEN-WORD RECOGNITION

Ava Creemers

Introduction

This chapter takes as a starting point the idea that listening and reading share modality-independent representations in the mental lexicon, and that, therefore, the two modalities each offer a window on the same abstract underlying representations. It is, however, an open question whether the differences between the modalities have actual consequences for the *processing* of morphologically complex words. The vast majority of psycholinguistic studies on morphological processing have examined morphological processing in visual word identification (for an overview, see Amenta & Crepaldi 2012, and Beyersmann & Grainger, this volume). For that reason, theories of morphological processing are typically reading theories; they model orthography in a given writing system (e.g., Taft 2004).

Research on morphological processing in *spoken-word recognition* is much scarcer, but has started to receive more attention in recent years. An increasing number of studies report that listeners show sensitivity to morphological structure during spoken-word recognition. This chapter discusses work on auditory morphological processing that, broadly speaking, falls into two categories. First, the chapter discusses research that addresses issues specific to the auditory modality, in particular how the incremental unfolding of the speech signal may affect the processing of morphologically complex words (e.g., Balling & Baayen 2012; Wurm 1997). Prefixed verbs have taken up a prominent role within this line of research, as they provide an interesting case with the prefix temporally preceding the stem in spoken language.

Second, the chapter discusses research that has direct parallels in the visual literature, both in terms of the particular topic and in terms of the methods. Considering that the majority of studies on visual morphological processing have been behavioral in nature and, in particular, have used primed lexical decision paradigms, this chapter's focus will

DOI: 10.4324/9781003159759-4

be restricted to priming studies as well. The chapter discusses the importance of these studies, as the specific properties of spoken and written language make that the results obtained in the visual modality cannot straightforwardly be assumed to hold in auditory processing. There are, in fact, good reasons to believe that the processing of lexical representations for written words may differ in crucial ways from those for spoken words (cf. Marslen-Wilson et al. 1994). By restricting ourselves to studies with parallels in the visual literature, we are able to compare morphological processing in the two modalities while highlighting new insights that are gained by looking at morphological processing not only in reading, but also in listening.

Morphological Processing in the Auditory Modality

Crucial differences between reading (written language) and listening (spoken language) make that the cognitive challenges that arise for readers and listeners may be fundamentally different (cf. Marslen-Wilson et al. 1994). This section focuses on the consequences of these differences for the processing of multi-morphemic words.

The most important difference between the modalities lies in their temporal structure. With visually presented words, the letters that make up a word are simultaneously presented and can, therefore, be simultaneously read, such that short-word stimuli are accessed as a whole (Adelman et al. 2010). Eye-tracking studies show that many morphologically complex words, at least those of eight characters or less, are typically read in one fixation only (Bertram 2011; Pollatsek & Hyönä 2010). This allows for stems and affixes to be processed simultaneously. In contrast, listening has a clear temporal and sequential dimension, such that the auditory speech signal unfolds continuously in time. The pieces making up a multi-morphemic word, therefore, arrive at the listener's ear at different, specifiable times. This means that listeners do not have access to the stem and affix of a complex word simultaneously. Rather, in prefixed words, the prefix is presented first with the onset of the stem following 200–300 ms or more later (e.g., Marslen-Wilson et al. 1994; Wurm 2000), and in suffixed words the stem precedes the presentation of the suffix.

It is not unreasonable to assume that the temporal differences between the visual and auditory modalities may have consequences for lexical access. It has, for instance, been proposed that the temporal unfolding of spoken suffixed words may give a head-start to accessing the stem separately from the suffix (e.g., Leminen et al. 2011), while the opposite may be expected for prefixed words. Note, however, that visual and auditory processing may be more similar to each other with longer words, as the way in which multi-morphemic words are read has been shown to depend on their length. In contrast to shorter words, longer words require multiple fixations, and the same may be true for low-frequency or novel words (e.g., Hyönä et al. 2020; Pollatsek & Hyönä 2010).[1]

A further consequence of the temporal differences between reading and listening is that a listener has very little control over the speed at which the input arrives. In addition, unlike with reading, auditory information does not remain available for later inspection. A listener cannot listen back to previous parts in the way that a reader can make a regressive eye movement. On the other hand, co-articulatory cues may be present in auditory processing, potentially signaling an upcoming suffix prior to the actual presentation of that suffix[2] (Goodwin Davies & Embick 2020). Echoic traces (i.e., sounds being retained in echoic memory) have also been argued to lead to a recall advantage for spoken words compared to written words, potentially explaining why larger semantic priming effects are found in auditory processing (Hutchison 2003). A further difference is that speaking rates, and as a consequence, listening rates, are much slower than reading rates. A lower estimate of the average silent reading rate for adults in English is 238 words per minute, while audiobooks are spoken at a rate of 140–180 words per minute (Brysbaert 2019).

Moreover, prosody plays an important role in spoken but not in written language. It is well-known that prosody may disambiguate otherwise ambiguous sentences and phrases (see, e.g., Dahan & Ferreira 2019), but the same can be true for word-level ambiguities. A Dutch prefixed verb like *door-lopen* (lit. "along-walk"), for instance, is ambiguous in its written form between a semantically transparent ("walk along") and opaque ("run through") meaning but may be disambiguated by lexical stress (*DOORlopen* and *doorLOPen*, respectively). For German compounds, it has been shown that the duration and the fundamental frequency of the first constituent are prosodic cues for determining whether the first constituent is the onset of a compound word or whether it represents a separate mono-morphemic word (Isel et al. 2003; Koester et al. 2004). Prosody has also been shown to signal a constituent's head or non-head status within compounds (Koester et al. 2009). These prosodic cues to morphological structure are unavailable to the reader.

Finally, Beyersmann et al. (2020) pointed out differences in sound-to-meaning vs. spelling-to-meaning mappings of morphologically complex words in languages such as English, German, and French.[3] These languages show a greater consistency in spelling compared to pronunciation of stems and affixes; compare, for instance, the spelling (*-ed*) and the pronunciation (/əd/, /d/, /t/) of the past tense suffix in English. Because morphological structure is more consistently represented in writing compared to speech in such languages, the identification of morphological structure might be less reliable in spoken compared to written language. Along these lines, it has been shown that orthographic consistency (i.e., orthographic depth) influences morphological processing (Mousikou et al. 2020). It is possible that the orthography-to-phonology mapping in a certain language may influence how closely related morphological processes in reading and listening are in that language.

Comparisons of Auditory and Visual Morphological Processing

The differences between the visual and auditory modalities make that the wealth of results that have been obtained from visual morphological processing cannot simply be extended to the auditory modality. However, direct comparisons between the modalities are scarce, such that it is difficult to tell whether the modality differences have consequences for how morphologically complex words are processed. Studies on morphological processing usually examine processing in either the visual or the auditory modality; only a few studies have directly compared visual and auditory processing. This is likely because it is not trivial to develop parallel experimental tasks in the two modalities. In comparing the modalities, results could be affected by task-specific effects of the different task formats (for a general discussion, see Wolf et al. 2019).

A case in point is the masked priming paradigm. The visual modality allows primes to be presented briefly (for 60 ms or less), making them virtually invisible to participants (Forster et al. 2003). Compared to written words, spoken words are much more difficult to mask. Kouider and Dupoux (2005) durationally compressed auditory primes and "masked" them within a stream of spectrally speech-like but unintelligible noise (see also Davis et al. 2010; Ussishkin et al. 2015). However, this method does not constitute a direct parallel to visual masking, making it hard to evaluate whether any potential differences between modalities are due to the different tasks and modality-specific methods, or due to the different modalities.

One area of morphological processing in which direct comparisons between spoken and written word recognition have been made is the Morpheme Interference Effect (MIE) (Beyersmann et al. 2020; Gafni et al. 2019; Leinonen et al. 2009; Taft et al. 1986). The MIE refers to the finding where pseudowords that are made up of real morphemes (e.g., *shoot-ment*) are rejected more slowly in a lexical decision task than pseudowords containing an invented morpheme (e.g., *shoot-mant*), which suggests that existing morphemes are activated even in pseudowords. In a study on English, Taft et al. (1986) reported increased lexical decision response times to nonwords that contained existing prefixes (e.g., *de-joice*) compared to those that did not (e.g., *te-joice*), with no difference in the pattern of results between the visual and the auditory tasks (see also Wurm 2000). More recently, Gafni et al. (2019) showed that the MIE generalizes across modalities in Hebrew as well, with robust MIEs in both modalities, although the visual MIE was consistently stronger than the auditory MIE. Beyersmann et al. (2020) examined the MIE in German and French and, in line with Gafni et al. (2019)'s results, also showed larger effects in the visual compared to the auditory modality. Based on these findings, Beyersmann et al. (2020) argued that stems and suffixes are identified and mapped onto existing morphemic representations more rapidly in the visual than in the auditory modality.

Other areas of morphological processing further suggest that there may be differences in the effects detected in the visual and auditory modalities. Masked priming effects for pseudo-suffixed words like *corner* have been argued to be orthographically driven (e.g., Rastle & Davis 2008, see Section 4 below). Another example is the comparison between repetition priming (e.g., *frog* → *frog*) and morphological priming (e.g., *frogs* → *frog*), for which some reported equal effect sizes (Forster et al. 1987; Stanners et al. 1979), while others reported greater facilitation for repetition priming than for (inflectional) morphological priming (Kouider & Dupoux 2009). Wilder et al.

(2019) proposed that the differences in results between these studies might be due to differences in modality, as the studies reporting no difference between repetition and morphological priming employed visual stimuli, whereas those reporting a difference were auditory.[4]

In sum, differences between the visual and auditory modalities may very well have consequences for morphological processing. Given the wealth of visual morphological processing studies, it is important to study morphological processing in the auditory modality as well. The next section discusses research on morphological processing that takes into account the temporal unfolding of the speech signal in the auditory modality, and how this informs us on the processing of spoken multi-morphemic words.

Continuous Processing or Decomposition?

The strict temporal order of the unfolding speech signal forms an important aspect of models of spoken-word recognition. The Cohort model (Marslen-Wilson 1984) proposed that the unfolding phonological input progressively narrows down the cohort until a Uniqueness Point (UP) is reached. The original UP was defined as the phoneme at which a given word deviates from all other words that share the same phonemes up to and including the phoneme preceding the UP. At this point, the word becomes uniquely distinguishable from its phonological cohort competitors. Uniqueness points play an important role in research into auditory morphological processing as well.

For the recognition of morphologically complex spoken words, two main types of approaches have been proposed. First, there are *continuous* approaches, which assume that auditory information is processed in a strictly linear way, regardless of word-internal morphological structure (e.g., Norris & McQueen 2008). Second, there are *decompositional* or *discontinuous* approaches, which assume a mechanism that takes into account morphological structure (Taft & Forster 1975; for a discussion, see Gwilliams and Marantz 2015). Prefixed words have been of particular interest to distinguish between decompositional and continuous approaches, since the prefix precedes the stem under auditory presentation. Under a decompositional approach, the recognition of a prefixed word occurs through activation of its stem, which is predicted to have a temporal cost associated with it, as the stem is preceded by the prefix (Marslen-Wilson et al. 1994). Under a continuous approach, all words—including morphologically complex ones—are handled as strings of phonemes without internal structure and are recognized from left to right at their uniqueness points.

Prefixed Words

Early work on morphological processing compared lexical decision times for free stems (e.g., *count*) and prefixed words (e.g., *miscount*) while manipulating the position of the UP (e.g., Meunier & Segui 2003; Schriefers et al. 1991; Tyler et al. 1988). Later work, however, pointed out that the original formulation of the UP may not be the most appropriate to study morphologically complex words (for discussion, see Balling & Baayen 2008, 2012; Wurm 1997; Wurm et al. 2006). Therefore, in Wurm (1997), a new identification point was introduced: the Conditional Root Uniqueness Point (CRUP), defined as the uniqueness point of the root morpheme in a prefixed word, given the prefix it occurs with. The CRUP of a prefixed word often falls at the same phoneme as its full-form UP, but it may also precede the UP. This is the case in a word like *discredit*, for which the CRUP occurs at the /r/, when the root *credit* becomes unique from all other free roots that can combine with the prefix *dis-* (e.g. *disclaim*). The UP for *discredit* falls at the second /d/, so that the CRUP precedes the UP.

Wurm and Ross (2001) showed that words in which the CRUP precedes the UP are recognized faster than words in which the CRUP and UP coincide (see also Wurm 1997, 2000; Wurm et al. 2006). Based on results like these, Wurm (1997) argued in favor of an approach in which morphologically complex words are simultaneously analyzed by two separate routes: a continuous route that processes whole words, and a decompositional route that takes into consideration morphological structure. Once the prefix is stripped off, the decomposition route attempts to match the remaining portion of the acoustic signal to a subset of the lexicon, namely to all free roots that have in the past combined with this particular prefix.

Other Derived Words

Balling and Baayen (2008, 2012) extended this line of work to suffixed words and compounds. As with prefixed verbs, they showed that there are two points at which the compatibility of the target word and the acoustic input influences auditory recognition. The first is the UP as formulated above, which is reached when morphologically unrelated competitors are no longer compatible with the acoustic input. The second is the Complex Uniqueness Point (CUP), at which morphologically related competitors become incompatible with the input. For suffixed words like *kindness*, the CUP occurs at the second /n/, when *kindness* deviates from other continuations like *kindhearted* and *kindly*, while the UP is at the first /n/, when *kindness* deviates from words like *kite*. The CUP is defined as the phoneme at which the target deviates from competitors that share its first constituent; therefore, it can easily be applied to compound and prefixed words as well. The CUP in a compound like *bedroom*, for instance, is at /u/, when *bedroom* deviates from other continuations like *bed roll* and *bed rail*. The CUP for prefixed words is very similar to Wurm's CRUP; for a prefixed word like *understand*, for instance, the CUP is at /æ/, when *understand* deviates from the group of words that share the same prefix (e.g., from words like *understate*).

The definition of the CUP is, hence, the same for different types of morphologically complex words, irrespective of whether the first constituent is a prefix, the stem of a suffixed word, or the first constituent of a compound. Balling and Baayen (2008) reported significant effects of both the UP and the CUP in auditory lexical decision to suffixed words in Danish. Balling and Baayen (2012) further showed that the effect of the CUP is as strong for suffixed words and compounds as it is for prefixed words. These results again show that both morphological and whole-word competitors play a role in spoken-word recognition, which suggests that spoken-word processing is sensitive to the internal morphological structure of words, at least to some extent.

The relevant question, then, is not whether words are ever decomposed in auditory processing, but under which conditions. This is discussed in the next section, which focuses in particular on the consequences of an auditory rather than visual presentation of stimuli.

Potential Influences on Decomposition

The conditions under which words may be decomposed or stored form an important research topic in both visual and auditory morphological processing studies, focusing in particular on the contributions of sub-word versus whole-word properties to word recognition. While the questions asked in studies of auditory processing are often similar to those in visual studies, the differences between the modalities as outlined in Section 2 make that it is unclear whether the same factors influence decomposition in both modalities.[5] This section focuses on three areas that have been looked at in the visual and auditory modalities, discussing the reasons why the effects in the two modalities may be different and the new insights gained from looking at morphological processing not only in the visual but also in the auditory modality.

Semantic Transparency

A prominent topic in discussions of what affects morphological processing is the extent to which a morphologically complex word is semantically related (or transparent) to the stem it is derived from. A wealth of studies has been produced in the visual modality, the results of which suggest that cross-linguistic differences may matter in whether morphological processing depends on semantic transparency (e.g., Günther et al. 2019). It has also been proposed that morphological processing may be more reliant on semantics in spoken-word processing compared to written-word processing, with visual processing being more heavily form-driven (Beyersmann et al. 2019; Marslen-Wilson et al. 1994; Wurm 1997, 2000; Wurm & Ross 2001). The fact that semantic priming effects for morphologically unrelated words are larger in the auditory compared to the visual modality provides additional support for this claim (Hutchison 2003).

It is conceivable, then, that morphological processing would depend on semantic transparency in spoken-word processing. Interestingly, this does not seem to be the case. Emmorey (1989) reported priming effects between auditorily presented morphological relatives that share a bound root but no semantic relationship (e.g., *submit* → *permit*), but no priming between purely phonological relatives (e.g., *balloon* → *saloon*). These results suggest that morphological information is processed irrespective of semantic transparency. In a study with prefixed verbs in Dutch, Creemers et al. (2020) also showed morphological priming effects in the absence of semantic transparency in an auditory–auditory paradigm, thereby replicating earlier German results reported in visual and cross-modal priming paradigms (Smolka et al. 2014). Dutch and German contain a large number of verb stems that appear with a small set of prefixes. These prefixed verbs may be semantically transparent, that is, directly related in meaning to the meaning that the stem has on its own (e.g., Dutch *aanbieden* "offer," with the stem *bieden*, also "offer"), or semantically opaque, with a meaning unrelated to the stem's (e.g., *verbieden* "forbid," with the same stem *bieden* "offer"). The results in Creemers et al. (2020) showed significant facilitation for both transparent and opaque pairs, while phonological controls ruled out the possibility that formal overlap was responsible for the observed priming effects (see also Creemers & Embick 2021).

Finally, Bacovcin et al. (2017) provided additional evidence for morphological processing in the absence of semantic overlap, using a feature of spoken language available only to a lesser extent in written language: rhyme priming. In addition to semantically opaque words, rhyme priming provides another way to avoid the confound that morphologically related words are often semantically related as well (e.g., *snow* and *snowed*). Bacovcin et al. (2017) used primes that rhymed with the target's stem, as opposed to the actual stem, to eliminate semantic confounds and control for phonological relatedness. Using prime–target pairs like *dough* → *snowed*, they examined whether *snow* is processed as part of processing *snowed*, in which case the recognition of *snowed* /snoʊd/ would be facilitated by the presentation of *dough* because *snow* /snoʊ/ and *dough* /doʊ/ rhyme. The results indeed showed that words like *snowed* were primed by words like *dough*, while mono-morphemes like *code* /koʊd/ were not.

These results suggest that, while it is still possible that spoken-word processing is more reliant on semantics compared to visual-word processing, morphological priming occurs also in the absence of semantic overlap or transparency. Due to the small sample of languages, however, it remains to be seen whether similar cross-linguistic differences as have been shown for the visual modality exist in auditory processing as well.[6]

Pseudo-Suffixed Words

One of the key findings in the visual morphological priming literature is that suffixed words (e.g., *teacher*) and pseudo-suffixed words (e.g., *corner*) both facilitate the recognition of the embedded words (*teach* and *corn*, respectively), while orthographic controls (e.g., *cashew* → *cash*) do not show these effects (e.g., Rastle et al. 2004). This finding has led to the proposal of a morpho-orthographic decomposition account, according to which the morpho-orthographic units of a complex word are analyzed in early visual word recognition before semantic information plays a role. This morpho-orthographic decomposition stage operates on the basis of orthography and not on the basis of true morphological structure (e.g., Rastle & Davis 2008). According to this approach, decomposition is performed whenever the visual system simultaneously detects a possible affix and stem, based on the orthographic transitional probabilities of letter clusters.

The focus of this line of research has long been solely on the visual processing of such pseudo-suffixed words. While, as discussed in Section 2, it is not trivial to develop an auditory behavioral parallel to the visual masked priming task, the processing of spoken pseudo-suffixed words has gained interest recently. Beyersmann et al. (2019), for instance, used the recording of Event-Related Potentials (ERPs) to monitor how processing unfolds over time when participants were making lexical decisions to French truly suffixed, pseudo-suffixed, and non-suffixed words. While space limitations prevent an in-depth discussion of the results, it is important to note that the concept of embeddings plays an important role in the interpretation of the auditory results. It is suggested that in spoken-word processing embedded words may always be activated, regardless of whether they are followed by an affix. In other words, morphological stems would then be activated when hearing truly suffixed words like *farmer*, pseudo-stems would be activated in pseudo-suffixed words like *corner*, and embeddings such as *cash* would also be activated in non-affixed words like *cashew*.

These results raise interesting further questions regarding the nature of the activation of embedded strings and the extent to which this mechanism is specific to auditory processing. It is plausible that the incremental unfolding of the speech signal causes the activation of embedded strings, which automatically leads to the question of whether different results would be obtained for word-final embeddings (e.g., *date* in *sedate*; see Zhang & Samuel 2015). Further research should also address whether embedding effects occur for all embeddings, or if these effects are modulated by characteristics such as the size of the part of the carrier word that the embedding takes up, and whether the embedding forms a separate syllable within the carrier word (e.g., Petrosino 2020). A related question is whether the activation of embeddings automatically results in the retrieval of lexical-semantic information (Zhang & Samuel 2015). Finally, further research into the auditory processing of these words will hopefully shine light on the extent to which these effects are (or are not) morphological in nature.

Affix Priming

Compared to stem priming, affix priming has received considerably less attention, and particularly in the auditory modality. However, if affixes have independent representations on par with stems, as typically assumed under decompositional approaches, facilitation through affix priming is expected between two forms sharing an affix (for further discussion, see Embick et al. 2021). The processing of affixes in spoken-word recognition is interesting for at least two reasons. First, as mentioned in Section 2, stems and affixes arrive at the listener's ear at different times due to the incremental nature of speech. In suffixed words, suffixes are encountered late (i.e., after presentation of the stem), making them an interesting phenomenon for the same reasons as stems in prefixed verbs (see Section 3). In addition, auditorily presented affixes are often prosodically weak, which holds especially for inflectional affixes. In English, affixes often do not bear stress and are shorter in duration than stems (see Goodwin Davies & Embick 2020; Wilder et al. 2019).

In an early study by Emmorey (1989), no significant priming effects were found for pairs of words that shared an inflectional suffix (e.g., *smil**ing*** → *break**ing***). Significant priming was found for pairs that shared a derivational suffix (e.g., *black**ness*** → *short**ness***), but similar effects were found for pairs that only shared final phonological segments (e.g., *tan**go*** → *car**go***). In contrast, more recently Goodwin Davies and Embick (2020) examined regular English plural suffixes in an auditory continuous lexical decision task. The results showed significant priming effects for inflectional affix priming (e.g., *crime**s*** → *tree**s***) relative to phonological (*clean**se*** → *tree**s***) and singular (*crime* → *tree**s***) controls. However, the size of the affix-priming effect was relatively small compared to identity priming for stems. While it is possible that the differences in magnitude of facilitation between stems and affixes are due to representational differences between stems and affixes, Goodwin Davies and Embick (2020) point out that priming effects are actually comparable between stems and affixes when the effect sizes are calculated as a percentage speed-up relative to the duration of a stem or affix. This illustrates the importance of taking into account modality-specific aspects of morphological processing under consideration, such as, in this case, the potential effects of the duration of the morpheme.

Conclusions

Research into the role of morphology in spoken-word recognition has gained interest over the past two decades, and a growing number of studies have shown that morphological structure plays a role in the processing of spoken morphologically complex words. This chapter stressed the importance of acknowledging potential modality effects in morphological processing. In particular, the modalities differ in their temporal structure: with auditory stimuli, the speech signal unfolds over time, while with visual stimuli the whole letter string is immediately available. The chapter also discussed further differences, such as prosody, co-articulatory cues, durational differences, and differences in sound-to-meaning and spelling-to-meaning mappings.

Section 4 described ways in which the differences between the two modalities may influence morphological processing by focusing on three areas that have been looked at in the visual and auditory modalities. I looked at how semantic effects have been argued to be larger in spoken-word processing, and how this may influence whether morphological processing depends on semantic transparency. I further discussed the potentially automatic activation of embedded words in auditory word processing, and the effects this may have on the processing of (pseudo-)

suffixed words. Finally, I reviewed how affix priming may differ across modalities due to the fact that affixes are prosodically weak. These topics illustrate that new insights may be gained by examining morphological processing not only in reading, but also in listening.

While the specific properties of speech prevent a straightforward application of results on visual morphological processing to auditory morphological processing, this chapter showed that the auditory modality also offers unique opportunities to study morphological processing. Section 3 discussed the way in which the temporal unfolding of prefixed verbs provides a crucial test case to distinguish between continuous processing models and decompositional ones. A further opportunity is provided by the slower nature of speech. This may provide listeners with a longer time window to process a stimulus, which, in turn, may make the auditory modality better suited to study the time-course of morphological processing. Along these lines, the recording of ERPs in the auditory modality has been used to monitor how morphological processes unfold over time (see, e.g., Beyersmann et al. 2019; Leminen et al. 2010).

A different direction for further research concerns the languages examined. While research on auditory processing of morphologically complex words has been growing over the past few years, the sample of languages studied is limited and comprises predominantly Indo-European languages such as English, French, and Dutch. In these languages, words are formed by linearly concatenating affixes and stems. In contrast, words in Semitic languages are typically composed of a discontiguous consonantal root and a word pattern that specifies vowels (i.e., non-concatenative morphology). In particular, spoken discontiguous roots provide an interesting perspective on the role of morphological structure, as the different letters of visually presented non-concatenative roots may still be processed simultaneously, while this is not the case with spoken words (see Oganyan et al. 2019 for Hebrew, Gwilliams and Marantz 2015 for Arabic, and Ussishkin et al. 2015 for Maltese).

While the focus of this chapter was on spoken-word recognition, not on visual-word recognition (i.e., reading), a model of morphological processing should ultimately account for both listening and reading (as well as speaking; see Tucker & Tomaschek, this volume). Since the vast majority of research has focused on the role that morphological structure plays in visual-word recognition, more research on spoken-word recognition is needed to provide a coherent picture of the morphological principles at work across modalities and the ways in which morphological processing may (or may not) differ in reading and listening.

Notes

1 Spoken-word recognition may also be more similar to visual-word recognition in younger and less-skilled readers, who are more likely to adopt a serial decoding strategy with more and longer fixations of smaller chunks of information (e.g., Blythe & Joseph 2011; Schroeder et al. 2015).

2 Similar to co-articulatory cues in spoken-word recognition, the use of parafoveal preview may provide readers some information about words or morphemes that have not yet been fixated.
3 See Amenta et al. (2017) for a comparison of the roles of Orthography-to-Semantics and Phonology-to-Semantics consistencies in visual-word recognition.
4 Note that, to avoid modality-specific effects, cross-modal priming is often used (e.g., Marslen-Wilson et al. 1994; Meunier & Segui 2002; Smolka et al. 2014). In a cross-modal priming experiment, subjects typically hear a spoken prime and make a lexical decision to a visually presented target. Without shared underlying representations or mechanisms, no priming from one modality to the other would be expected. Therefore, cross-modal priming avoids effects related to low-level, modality-specific perceptual processes (Allen & Badecker 2002), and priming effects are assumed to reflect modality-independent representations and processes. As this chapter focuses on auditory processing, and since cross-modal studies typically include visual targets, cross-modal studies will not be further discussed here.
5 This chapter glosses over the different senses of what it means to represent or process a word as decomposed. See Embick et al. (2021) for a discussion and an outline of a finer-grained set of questions regarding decomposition.
6 See Creemers et al. (2020) for a discussion on the different materials used for different languages, and the potential implications for cross-linguistic differences in morphological processing.

References

Adelman, J. S., Marquis, S. J., & Sabatos-DeVito, M. G. (2010). Letters in words are read simultaneously, not in left-to-right sequence. *Psychological Science*, 21 (12), 1799–1801. doi:10.1177/0956797610387442.

Allen, M., & Badecker, W. (2002). Inflectional regularity: Probing the nature of lexical representation in a cross-modal priming task. *Journal of Memory and Language*, 46 (4), 705–722. doi:10.1006/jmla.2001.2831.

Amenta, S., & Crepaldi, D. (2012). Morphological processing as we know it: An analytical review of morphological effects in visual word identification. *Frontiers in Psychology*, 3 (232). doi:10.3389/fpsyg.2012.00232.

Amenta, S., Marelli, M., & Sulpizio, S. (2017). From sound to meaning: Phonology-to-semantics mapping in visual word recognition. *Psychonomic Bulletin & Review*, 24 (3), 887–893. doi:10.3758/s13423-016-1152-0.

Bacovcin, H. A., Goodwin Davies, A., Wilder, R. J., & Embick, D. (2017). Auditory morphological processing: Evidence from phonological priming. *Cognition*, 164, 102–106. doi:10.1016/j.cognition.2017.03.011.

Balling, L. W., & Baayen, R. H. (2008). Morphological effects in auditory word recognition: Evidence from Danish. *Language and Cognitive Processes, 23* (7–8), 1159–1190. doi:10.1080/01690960802201010.

Balling, L. W., & Baayen, R. H. (2012). Probability and surprisal in auditory comprehension of morphologically complex words. *Cognition*, 125 (1), 80–106. doi:10.1016/j.cognition.2012.06.003.

Bertram, R. (2011). Eye movements and morphological processing in reading. *The Mental Lexicon*, 6 (1), 83–109. doi:10.1075/ml.6.1.04ber.

Beyersmann, E., Bolger, D., Pattamadilok, C., New, B., Grainger, J., & Ziegler, J. C. (2019). Morphological processing without semantics: An ERP study with spoken words. *Cortex*, 116, 55–73. doi:10.1016/j.cortex.2019.02.008.

Beyersmann, E., Mousikou, P., Javourey-Drevet, L., Schroeder, S., Ziegler, J. C., & Grainger, J. (2020). Morphological processing across modalities and languages. *Scientific Studies of Reading*, 24 (6)500–519. doi:10.1080/10888438.2020.1730847.

Blythe, H. I., & Joseph, H. S. S. L. (2011). Children's eye movements during reading. In S. P. Liversedge, I. D. Gilchrist, & S. Everling (Eds.), *The Oxford handbook of eye movements* (pp. 643–662). Oxford: Oxford University Press.

Brysbaert, M. (2019). How many words do we read per minute? A review and meta-analysis of reading rate. *Journal of Memory and Language*, 109 (104047). doi:10.1016/j.jml.2019.104047.

Creemers, A., & Embick, D. (2021). Retrieving stem meanings in opaque words during auditory lexical processing. *Language, Cognition and Neuroscience*, 36 (9), 1107–1122. doi:10.1080/23273798.2021.1909085.

Creemers, A., Goodwin Davies, A., Wilder, R. J., Tamminga, M., & Embick, D. (2020). Opacity, transparency, and morphological priming: A study of prefixed verbs in Dutch. *Journal of Memory and Language*, 110, 104055. doi:10.1016/j.jml.2019.104055.

Dahan, D., & Ferreira, F. (2019). Language comprehension: Insights from research on spoken language. In P. Hagoort (Ed.), *Human language: From genes and brains to behavior* (pp. 21–33). Cambridge, MA: MIT Press.

Davis, C., Kim, J., & Barbaro, A. (2010). Masked speech priming: Neighborhood size matters. *The Journal of the Acoustical Society of America*, 127 (4), 2110–2113. doi:10.1121/1.3353116.

Embick, D., Creemers, A., & Goodwin Davies, A. (2021). Morphology and the mental lexicon: Three questions about decomposition. In A. Papafragou, J. C. Trueswell, and L. R. Gleitman (Eds.), *The Oxford handbook of the mental lexicon* (pp. 77–97). Oxford: Oxford University Press.

Emmorey, K. D. (1989). Auditory morphological priming in the lexicon. *Language and Cognitive Processes*, 4 (2), 73–92. doi:10.1080/01690968908406358.

Forster, K. I., Davis, C., Schoknecht, C., & Carter, R. (1987). Masked priming with graphemically related forms: Repetition or partial activation? *The Quarterly Journal of Experimental Psychology*, 39 (2), 211–251. doi:10.1080/14640748708401785.

Forster, K. I., Mohan, K., & Hector, J. (2003). The mechanics of masked priming. In S. Kinoshita & S. J. Lupker (Eds.), *Masked priming: The state of the art* (pp. 3–37). New York: Psychology Press.

Gafni, C., Yablonski, M., & Ben-Shachar, M. (2019). Morphological sensitivity generalizes across modalities. *The Mental Lexicon*, 14 (1), 37–67. doi:10.1075/ml.18020.gaf.

Goodwin Davies, A., & Embick, D. (2020). The representation of plural inflectional affixes in English: Evidence from priming in an auditory lexical decision task. *Language, Cognition and Neuroscience*, 35 (3), 393–401. doi:10.1080/23273798.2019.1684528.

Günther, F., Smolka, E., & Marelli, M. (2019). "Understanding" differs between English and German: Capturing systematic language differences of complex words. *Cortex*, 116, 168–175. doi:10.1016/j.cortex.2018.09.007.

Gwilliams, L. E., & Marantz, A. (2015). Non-linear processing of a linear speech stream: The influence of morphological structure on the recognition of spoken Arabic words. *Brain and Language*, 147, 1–13. doi:10.1016/j.bandl.2015.04.006.

Hutchison, K. A. (2003). Is semantic priming due to association strength or feature overlap? A microanalytic review. *Psychonomic Bulletin & Review*, 10 (4), 785–813. doi:10.3758/BF03196544.

Hyönä, J., Pollatsek, A., Koski, M., & Olkoniemi, H. (2020). An eye-tracking study of reading long and short novel and lexicalized compound words. *Journal of Eye Movement Research*, 13 (4). doi:10.16910/jemr.13.4.3.

Isel, F., Gunter, T. C., & Friederici, A. D. (2003). Prosody-assisted head-driven access to spoken German compounds. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 29 (2), 277–288. doi:10.1037/0278-7393.29.2.277.

Koester, D., Gunter, T. C., Wagner, S., & Friederici, A. D. (2004). Morphosyntax, prosody, and linking elements: The auditory processing of German nominal compounds. *Journal of Cognitive Neuroscience*, 16 (9), 1647–1668. doi:10.1162/0898929042568541.

Koester, D., Holle, H., & Gunter, T. C. (2009). Electrophysiological evidence for incremental lexical-semantic integration in auditory compound comprehension. *Neuropsychologia*, 47 (8–9), 1854–1864. doi:10.1016/j.neuropsychologia.2009.02.027.

Kouider, S., & Dupoux, E. (2005). Subliminal speech priming. *Psychological Science*, 16 (8), 617–625. doi:10.1111/j.1467-9280.2005.01584.x.

Kouider, S., & Dupoux, E. (2009). Episodic accessibility and morphological processing: Evidence from long-term auditory priming. *Acta Psychologica*, 130 (1), 38–47. doi:10.1016/j.actpsy.2008.09.011.

Leinonen, A., Grönholm-Nyman, P., Järvenpää, M., Söderholm, C., Lappi, O., Laine, M., & Krause, C. M. (2009). Neurocognitive processing of auditorily and visually presented inflected words and pseudowords: Evidence from a morphologically rich language. *Brain Research*, 1275, 54–66. doi:10.1016/j.brainres.2009.03.057.

Leminen, A., Leminen, M. M., & Krause, C. M. (2010). Time course of the neural processing of spoken derived words: An event-related potential study. *Neuroreport*, 21 (14), 948–952. doi:10.1097/WNR.0b013e32833e4b90.

Leminen A., Leminen, M., Lehtonen M., Nevalainen P., Ylinen S., Kimppa L., Sannemann, C., Mäkelä, J. P., & Kujala, T. (2011). Spatiotemporal dynamics of the processing of spoken inflected and derived words: A combined EEG and MEG study. *Frontiers in Human Neuroscience*, 5 (66). doi:10.3389/fnhum.2011.00066.

Marslen-Wilson, W. D. (1984). Function and process in spoken word recognition. In H. Bouma & D. Bouwhuis (Eds.), *Attention and performance x: Control of language processes* (pp. 125–150). Hove, UK: Lawrence Erlbaum Associates.

Marslen-Wilson, W. D., Tyler, L. K., Waksler, R., & Older, L. (1994). Morphology and meaning in the English mental lexicon. *Psychological Review*, 101 (1), 3–33. doi:10.1037/0033-295X.101.1.3.

Meunier, F., & Segui, J. (2002). Cross-modal morphological priming in French. *Brain and Language*, 81 (1), 89–102. doi:10.1006/brln.2001.2509.

Meunier, F., & Segui, J. (2003). Identification of spoken prefixed words in French. In R. H. Baayen & R. Schreuder (Eds.), *Morphological structure in language processing* (Vol. 151, pp. 337–354). Berlin: Mouton de Gruyter.

Mousikou, P., Beyersmann, E., Ktori, M., Javourey-Drevet, L., Crepaldi, D., Ziegler, J. C., Grainger, J. & Schroeder, S. (2020). Orthographic consistency influences morphological processing in reading aloud: Evidence from a cross-linguistic study. *Developmental Science*, 23 (6), e12952. doi:10.1111/desc.12952.

Norris, D., & McQueen, J. M. (2008). Shortlist B: A Bayesian model of continuous speech recognition. *Psychological Review*, 115 (2), 357–395. doi:10.1037/0033-295X.115.2.357.

Oganyan, M., Wright, R., & Herschensohn, J. (2019). The role of the root in auditory word recognition of Hebrew. *Cortex*, 116, 286–293. doi:10.1016/j.cortex.2018.06.010.

Petrosino, R. (2020). *More than islands of regularity: An investigation of the sensitivity of morphological decomposition to higher-level linguistic properties*, Doctoral dissertation, University of Connecticut.

Pollatsek, A., & Hyönä, J. (2010). Processing of morphemically complex words in context: What can be learned from eye movements? In S. Andrews (Ed.), *From inkmarks to ideas: Current issues in lexical processing* (pp. 305–328). New York: Psychology Press.

Rastle, K., & Davis, M. (2008). Morphological decomposition based on the analysis of orthography. *Language and Cognitive Processes*, 23 (7–8), 942–971. doi:10.1080/01690960802069730.

Rastle, K., Davis, M., & New, B. (2004). The broth in my brother's brothel: Morpho-orthographic segmentation in visual word recognition. *Psychonomic Bulletin & Review*, 11 (6), 1090–1098. doi:10.3758/bf03196742.

Schriefers, H., Zwitserlood, P., & Roelofs, A. (1991). The identification of morphologically complex spoken words: Continuous processing or decomposition? *Journal of Memory and Language*, 30 (1), 26–47. doi:10.1016/0749-596X(91)90009-9.

Schroeder, S., Hyönä, J., & Liversedge, S. P. (2015). Developmental eye-tracking research in reading: Introduction to the special issue. *Journal of Cognitive Psychology*, 27 (5), 500–510. doi:10.1080/20445911.2015.1046877.

Smolka, E., Preller, K. H., & Eulitz, C. (2014). "Verstehen" ("understand") primes "stehen" ("stand"): Morphological structure overrides semantic compositionality in the lexical representation of German complex verbs. *Journal of Memory and Language*, 72, 16–36. doi:10.1016/j.jml.2013.12.002.

Stanners, R. F., Neiser, J. J., Hernon, W. P., & Hall, R. (1979). Memory representation for morphologically related words. *Journal of Verbal Learning and Verbal Behavior*, 18 (4), 399–412. doi:10.1016/S0022-5371(79)90219-6.

Taft, M. (2004). Morphological decomposition and the reverse base frequency effect. *Quarterly Journal of Experimental Psychology Section A*, 57 (4), 745–765. doi:10.1080/02724980343000477.

Taft, M., & Forster, K. I. (1975). Lexical storage and retrieval of prefixed words. *Journal of Verbal Learning and Verbal Behavior*, 14 (6), 638–647. doi:10.1016/S0022-5371(75)80051-X.

Taft, M., Hambly, G., & Kinoshita, S. (1986). Visual and auditory recognition of prefixed words. *The Quarterly Journal of Experimental Psychology Section A*, 38 (3), 351–365. doi:10.1080/14640748608401603.

Tyler, L. K., Marslen-Wilson, W., Rentoul, J., & Hanney, P. (1988). Continuous and discontinuous access in spoken word-recognition: The role of derivational prefixes. *Journal of Memory and Language*, 27 (4), 368–381. doi:10.1016/0749-596X(88)90062-9.

Ussishkin, A., Dawson, C. R., Wedel, A., & Schluter, K. (2015). Auditory masked priming in Maltese spoken word recognition. *Language, Cognition and Neuroscience*, 30 (9), 1096–1115. doi:10.1080/23273798.2015.1005635.

Wilder, R. J., Goodwin Davies, A., & Embick, D. (2019). Differences between morphological and repetition priming in auditory lexical decision: Implications for decompositional models. *Cortex*, 116, 122–142. doi:10.1016/j.cortex.2018.10.007.

Wolf, M. C., Muijselaar, M. M., Boonstra, A., & de Bree, E. H. (2019). The relationship between reading and listening comprehension: Shared and modality-specific components. *Reading and Writing*, 32 (7), 1747–1767. doi:10.1007/s11145-018-9924-8.

Wurm, L. H. (1997). Auditory processing of prefixed English words is both continuous and decompositional. *Journal of Memory and Language*, 37 (3), 438–461. doi:10.1006/jmla.1997.2524.

Wurm, L. H. (2000). Auditory processing of polymorphemic pseudowords. *Journal of Memory and Language*, 42 (2), 255–271. doi:10.1006/jmla.1999.2678.

Wurm, L. H., Ernestus, M. T., Schreuder, R., & Baayen, R. H. (2006). Dynamics of the auditory comprehension of prefixed words: Cohort entropies and conditional root uniqueness points. *The Mental Lexicon*, 1 (1), 125–146. doi:10.1075/ml.1.1.08wur.

Wurm, L. H., & Ross, S. E. (2001). Conditional root uniqueness points: Psychological validity and perceptual consequences. *Journal of Memory and Language*, 45 (1), 39–57. doi:10.1006/JMLA.2000.2758.

Zhang, X., & Samuel, A. G. (2015). The activation of embedded words in spoken word recognition. *Journal of Memory and Language*, 79, 53–75. doi:10.1016/j.jml.2014.12.001.

5

THE ROLE OF SEMANTICS IN THE PROCESSING OF COMPLEX WORDS

Marco Marelli

Introduction

The relationship between morphology and semantics has deep, long-standing foundations. Morphemes have been described as form units that are linked to semantic units (i.e., *sememes*, Bloomfield, 1933) or outright meaning-bearing elements ("the smallest individually meaningful elements in the utterances of a language"; Hockett, 1958). This characterization agrees with our intuitions as speakers of a language: if we hear the pseudo-word *quickify*, we have no troubles associating it to the "make something or someone quick" meaning, even if we have never encountered that sequence of sounds before; also, we can make a clear distinction between words like *cooker* and words like *brother*, since we can appreciate how the former is semantically related to *cook* and how the latter is not semantically related to *broth*. These observations suggest that morphologically complex words cannot be reduced to concatenations of frequent phoneme/grapheme chunks, since these very chunks have a crucial role in word comprehension.

Despite morphemes evidently taking up a role in characterizing the semantics of a word, the psycholinguistic research on the semantic impact in complex-word processing has a troubled history. Even if the semantic informativeness of morphemic structure has been typically acknowledged (e.g., Rastle & Davis, 2008), for a series of empirical and theoretical reasons the morphological-processing literature has been largely focused on the word-form level, especially in the domain of visual-word recognition. This chapter will first present results supporting a semantics-independent representation of morphemes and the evidence (or lack thereof) for a role for morpheme meanings in word processing. Second, it will discuss how the ensuing conundrum may be solved by adopting different perspectives in evaluating semantic effects. Finally, it will describe a series of

DOI: 10.4324/9781003159759-5

computational developments that can offer an explanation for the inconsistencies of the semantic impact in morphological processing.

Inconsistency of Semantic Effects in Morphological Priming

The role of semantics in the processing of complex words is addressed relatively early on in the morphological processing literature. The reason is simple: much of the research has addressed the question as to whether morphological information is independently represented in the speaker's mind. However, due to the very nature of morphology as something in-between form and meaning, in order to provide evidence for morphemic representations one must rule out that morphology-related effects cannot be accounted for by overlap in orthography, phonology, and, crucially, semantics. Evidence in this respect was provided via priming paradigms in, for example, the works carried out by Marslen-Wilson et al. (1994), Feldman and Soltano (1999), and Feldman (2000). In these studies, participants were asked to evaluate as fast as possible the lexicality of a target stimulus (which could be either a word - *vow* or a nonword - *wug*). Such targets were preceded by a different word, namely the *prime*. If responses are faster to pairs of words related to each other vis-à-vis pairs of words without such a relation, then one can conclude that such a relation is psychologically real, in the sense that it must be represented at some cognitive level. Pairs of stimuli entertaining a morphological relationship (*vowed-vow*) were considered along with orthographically similar pairs (*vowel-vow*) and pairs of words related in meaning (*pledge-vow*). Crucially, the facilitation observed for morphologically related pairs with respect to an unrelated baseline (i.e., the priming effect) was larger for the morphological condition than for both the semantic and the orthographic conditions. Indeed, in Feldman (2000) the priming effect for morphological pairs was even larger than the summed-up facilitation from the form pairs and the semantic pairs. Such evidence indicates that the impact of morphological relations on word processing cannot be reduced to the combined effect of form and meaning overlap, but seems to have a special status in the cognitive processes characterizing our comprehension of words: in particular, morphology seems be reflected in psychological processes that go beyond the simple semantic relatedness between words: *dealer* would facilitate the processing of *deal* not (only) because of their mutual meaning association.

Such dissociation between morphology and semantics, and hence the meaning-independent effect of morphology on word processing, has been further supported by a number of studies investigating semantic transparency, a topic at the center of one of the most heated debates of the past few decades within the morphological processing community. With "semantic transparency," one denotes the extent to which a morphologically complex word can be comprehended on the basis of the meaning of its constituent morphemes. For example, a word like *cooker* might be considered highly transparent, since its meaning is related to the meaning of the embedded stem (*cook*). On the other hand, a word like *brother* is typically considered opaque, since the embedded pseudo-stem (*broth*) has not much to do with the whole-word meaning (Marslen-Wilson et al., 1994). Such a measure does not only apply to derivation, but can also characterize compound words (Libben, 1998; Sandra, 1990; Zwitserlood, 1994): one can find transparent compounds (*car-park*), opaque compounds (*hogwash*), and even semi-transparent compounds, where only one constituent is semantically related to the whole word (*staircase, jailbird*).

Although semantic transparency may feel like an important variable when it comes to understanding complex words, and it has received a due amount of attention because of this, in terms of empirical evaluation the evidence in favor of its importance has not been conclusive. In typical, long-term priming with derived words, a transparency effect is often observed (Feldman & Soltano, 1999; Marslen-Wilson et al., 1994; Rueckl & Aicher, 2008). However, works using masked priming, that were extensively applied to the investigation of this issue, did not confirm such results. In a masked-priming paradigm, the word prime is presented for a very short time (typically under 50 ms) between a forward mask and the word target. Under these conditions, the prime is virtually invisible, and it is hence considered an ideal setting to investigate the impact of lexical properties without an explicit awareness of word-to-word relations affecting the process (Forster, 1998); that is, if a priming effect is observed under these conditions, it must depend on the automatic processing of the prime word, and not on the participants noticing some association between the latter and the target. Moreover, masked priming is believed to capture early processing steps (Marelli et al., 2020), bringing to the table a timing sensitivity that is deemed particularly important for the development of morphological processing models (Amenta & Crepaldi, 2012).

Semantics does not seem to have a large impact in masked priming studies on morphologically complex words (Rastle & Davis, 2008). In these works, a transparent condition (where prime–target pairs entail a semantic and morphological relation; *dealer-deal*) is contrasted with an opaque condition (where prime and target have an apparent morphological association but no semantic relation; *brother-broth*) and an orthographic condition (where prime and target have an orthographic overlap but no morphological or semantic relation; *scandal-scan*). Results typically show a priming effect in both the transparent and the opaque conditions, whereas no facilitation is observed in the orthographic condition (Longtin et al., 2003; Marslen-Wilson et al., 2008; Rastle et al., 2004). Whether there is a difference in facilitation between the transparent and the opaque condition is still debated; indeed, there are a number of studies finding a further boost in response times when presented with a transparent pair vis-à-vis an opaque one (e.g., Feldman et al., 2015; Feldman et al., 2009). However, the difference between the opaque and the orthographic conditions remains largely unchallenged. This pattern is particularly striking, since it suggests that any word that is apparently complex will be treated as such, irrespective of it actually having a morphological structure informing word meaning (Davis & Rastle, 2010). Therefore, it seems that even a word like *corner*, which has nothing to do with *corn*, will be processed as composed by *corn* and *-er*. These pieces of evidence have led to the "semantically blind decomposition" proposal

(Rastle & Davis, 2008), according to which every letter string constituted by an apparent concatenation of morphemes will trigger access to these very sublexical units during word recognition. The blind decomposition view, although not unchallenged (e.g., Feldman et al., 2009), has been very popular in the morphological-processing community, and led to the widespread idea that morpheme meanings do not play any role during the early stages of complex-word processing: an initial morpheme-based segmentation, not modulated by word meaning, would be triggered every time a (apparently) complex word is encountered, and only subsequently followed by semantic activation (Amenta & Crepaldi, 2012; Davis & Rastle, 2010).

The marginal role for semantic information in morphological processing is also supported by a number of studies documenting a lack of a semantic transparency effects even in paradigms adopting long-term priming. A case in point is that a number of papers report that, in German, a priming effect can be observed for complex verbs even when these are semantically opaque (*verstehen-stehen, understand-stand*; Smolka et al., 2009; Smolka et al., 2014), in a way that is remarkably similar to what was cross-linguistically shown for derived words using the masked priming paradigm in, for example, French and English. This very pattern is again found when considering compound words. Compound-word processing has been extensively investigated using a constituent-priming paradigm in which the compound is presented as a target and can be preceded by either constituent as a prime word (for example, *car-carwash* or *wash-carwash*). These investigations revealed robust cross-linguistic evidence for a constituent-priming effect, largely independent from the constituent position within the compound (i.e., first constituent vs. second constituent). Crucially, the constituent-priming effect seems also to be independent of the semantic transparency of the target compound: irrespective of the compound being transparent, opaque, or semi-transparent (*carwash* vs. *hogwash* vs. *jailbird*) its recognition is facilitated by the previous presentation of one of its constituents (Libben et al., 2003; Zwitserlood, 1994). Importantly, this pattern emerges from both long-term priming paradigms and masked-priming paradigms (Shoolman & Andrews, 2003; Fiorentino & Fund-Reznicek, 2009).

A confirmation of the semantics-less nature of morphological processing seems to be found also in works involving complex pseudo-words—that is, concatenations of morphemes that are not attested in a given language (e.g., *quickify*). When these stimuli are included as primes in a masked priming study, a priming effect is routinely observed (Longtin & Meunier, 2005), even if there is in principle no semantic relation between the pseudo-complex prime and its pseudo-stem target (*quick*), since no familiar meaning is associated to a pseudo-word like *quickify* to begin with. Further evidence in the nonword domain comes from the "morpheme interference" effect (Crepaldi, et al. 2013; Taft & Forster, 1976): when rejecting a nonword in a lexical decision task, it takes longer to refute a complex pseudoword (a non-attested concatenation of familiar morphemes: *dustworth*) than a simple nonword (*mowdflisk*). This effect is typically explained on the basis of the familiarity with the sublexical units: it is more difficult to indicate *dustworth* as a nonword because it is formed by elements that are known to the speaker. Semantics seems to play no role in determining such a phenomenon—in the speaker's experience, no meaning is associated to the presented letter string.

"And Yet It Moves": Evidence for a Semantic Impact in Morphological Processing

Taken together, the described pieces of evidence seem to speak for a principled separation of morphological and semantic aspects, and a limited role for the latter during morphological processing. It is not surprising, then, that the morphological-processing research has tended to focus on form-level effects and to provide form-level interpretations, especially in the domain of visual-word recognition (Amenta & Crepaldi, 2012). However, a number of studies have tried to vary the methods through which semantic effects are gauged, as well the characterization of some of the key variables investigated. The results of these studies tell a rather different story.

A clear example in this respect is the effect of family size (De Jong et al., 2000): the ease of the processing of a word is influenced by the number of morphological relatives (i.e., words sharing the same constituent morphemes) the word has. Words with larger family sizes are associated with shorter processing times. This is observed in a number of tasks, including lexical decision (Bertram et al., 2000; Schreuder & Baayen, 1997), reading sentences for comprehension (Kuperman et al., 2008), and also timed sensibility judgments (Günther, Petilli et al., 2020). Remarkably, the effect is not only found for morphologically complex words, but even for simple ones (Schreuder & Baayen, 1997), speaking for an automatic activation of morphological information during word processing, irrespective of the experiment purpose. Why is the family-size effect considered an index of semantic impact? It was shown that better family-size estimates can be obtained if opaque complex words are excluded by the family count; such estimates will explain more variance in behavioral data than measures comprehensive of any morpho-orthographic relations (Bertram et al., 2000). Furthermore, in bilingual speakers family size in L1 is predictive of response times for the processing of corresponding words in L2 (Moscoso del Prado Martín et al., 2005), indicating that the variable must act at a higher, conceptual level. Family size hence speaks for an entanglement of morphological and semantic information in word processing, to the point that morpheme and morphological relations seem to be semantically characterized. In line with this interpretation, it has been shown that, even in the context of blind decomposition, morpheme meanings tend to be accessed. In other words, it might be the case that semantic transparency has a limited impact on the activation of constituent morphemes, but this does not exclude the notion that these very morphemes, once activated, are semantically connoted. For example, it has been shown that in a masked-priming paradigm an opaque prime like *butterfly* can facilitate the recognition of the target *bread*, which is semantically related to a constituent morpheme of the complex prime (Tsang & Cheng, 2014; for converging evidence from a different task, see also Hasenäcker et al., 2020).

The impact of meaning in the processing of morphologically complex words also emerges when, while characterizing morphological structures, one considers semantically connoted aspects that are more fine-grained than semantic transparency. In fact, it must be noted that the relation between the complex-word meaning and its constituent morphemes is far from being the only piece of semantic information brought about by morphology. This is particularly evident when considering compound words, whose meaning emerges from an articulated (and largely implicit) relational structure binding the meanings of the two embedded constituents (Bisetto & Scalise, 2005). In fact, most compounds are characterized by a hierarchical structure, with one constituent acting as the head of the compound, carrying most of the lexical and semantic information, and defining the category the compound belongs to (a *mountain magazine* is a type of *magazine*), and the other acting as modifier, further specifying the compound meaning and defining its subcategory (a *mountain magazine* is a magazine that has something to do with *mountains*).[1] In Germanic languages (including English), compounds have a typical modifier-head structure, where the final constituent tends to take the head role and the initial constituent tends to take the modifier role. This does not necessarily hold for other languages—for example, in Romance languages one can find both head-initial and head-final compounds (Guevara & Scalise, 2009). Whatever the compound structure, a speaker needs to assign the modifier and head roles in order to produce an interpretation for the processed compound. Indeed, there is a vast amount of psycholinguistic evidence pointing to the importance of the modifier-head structure in compound processing. For example, in a priming paradigm where compounds are presented both as primes and as targets, responses are facilitated more when the target shares its head constituent with the prime (*ham soup – honey soup*) as opposed to when the target and the prime share the modifier (*honey bee – honey soup*) (Gagné, 2001), showing that the different roles played by either constituent are taken into account when processing a compound word (Gagné et al. 2009). Indeed, further evidence in this respect can be found when investigating Italian compounds, which can be either head-initial (*pescespada, swordfish*) or head-final (*astronave, starship*). The compound type is found to modulate priming effects as well as fixation times in reading, indicating that the underlying structure must be identified in order to properly process the compound (Marelli et al., 2009; Marelli & Luzzatti, 2012).

Further evidence in this respect comes from the well-documented impact of the unexpressed modifier-head relation on behavioral responses. In fact, in English, the way the modifier and the head constituents are linked to each other is varied, to say the least. Take, for example, *snow man* and *snow shovel*. While the former is typically interpreted as "*a man MADE OF snow*," the latter elicits the "*a shovel USED FOR snow*" interpretation. Importantly, the relation between the constituents is not lexically expressed, and is left to the intuition of the speaker. Nevertheless, for many compounds (even unfamiliar ones!) speakers have a clear and consistent intuition as to which relation best describes them (Schäfer & Bell, 2020). This further structural effect does not only emerge in explicit intuitions, but also affects responses when reading compounds, indicating that it plays a central role in word processing. For example, in the compound-to-compound priming experiment described above (Gagné, 2001), a relational-priming effect is observed: if prime and target share the same modifier, a response boost is observed when they also share the same relation: the priming effect is larger when processing *honey soup – honey cake* than when processing *honey bee – honey cake*. Consistent results are also found when considering the processing of compounds in isolation (Gagné & Shoben, 1997): it is easier to process a compound whose relation is typical for its embedded modifier (*plastic bottle* with the relation MADE OF, which is typical for *plastic*) than compounds characterized by an atypical relation (*plastic crisis*, with the relation CAUSED BY, which is atypical for *plastic*); moreover, the more the relational competition (i.e., the more there are potentially plausible relations), the more difficult it is to process the corresponding compound (Schmidtke et al., 2016). Together with the evidence in favor of an impact of the modifier-head roles, these results speak for the idea that articulated semantic dynamics are at play when processing complex words and invite us to reconsider the idea of limited semantic information associated to morphology.

This evidence on compound words suggests that the semantic counterpart of morphological processing is better characterized as a meaning-composition process, in which word meaning is actively induced by combining together the semantic information associated to each constituent morpheme (Ji et al., 2011; Marelli & Luzzatti, 2012). Such a perspective encourages a different point of view also when dealing with semantic transparency (Marelli et al., 2015), which may explain the inconsistent results emerging from the literature. Most of the works have in fact looked at semantic transparency as the semantic relation between independent, encapsulated meanings: the transparency of, for example, *speaker*, is typically operationalized as the perceived degree of semantic association between *speak* and *speaker*. However, this approach treats semantic transparency as merely a measure of meaning relatedness, with no actual role for morphological information, and in which the derived or compound word is not actually treated as morphologically complex: the semantic transparency of *speaker* is treated in the same way one would treat the semantic relatedness between *cat* and *dog*, not taking into account that *speaker* is a morphologically complex word. What if we look at semantic transparency from a compositional perspective—that is, as the ease of integration of the constituent morphemes into a complex meaning? Indeed, when examining the body of research on semantic transparency a pattern seems to emerge: if transparency is operationalized in meaning-composition terms, a transparency effect on behavioral responses tends to emerge. For example, Marelli & Luzzatti (2012) showed that transparency can be measured by asking participants to rate to what extent the meaning of a complex word can be induced by combining the meanings of its morphemes. The obtained measure is demonstrated to explain processing data (response times for isolated compounds and reading times for compounds in sentence contexts), whereas a more traditional transparency measure (elicited by asking "to what extent is the complex word meaning related to the meaning of its constituent morpheme?") fails to do so. Remarkably, such a compositional-transparency measure also interacts with the modifier-head structure in determining behavioral responses, further indicating the importance of framing semantic transparency from a composition perspective.

Meaning-composition processes can be also forced (or, at the very least, encouraged) via experimental manipulations. Coherently with the evidence described above, when such processes are triggered a transparency effect tends to be amplified. For example, Ji et al. (2011) showed, in a series of experiments, that task manipulations favoring semantic integration make opaque compounds more difficult to process. In a series of lexical decision experiments, the morphological structure of the word was made more evident by, for example, separating the constituents with a blank space or writing them in different colors. Under these conditions, the responses to opaque compounds became longer, indicating a time-consuming conflict-resolution attempt elicited by the decomposition and recombination process. In other words, making it evident that the presented words were composed by two constituents would have favored an active meaning-combination process; this, in turn, would have led to a "wrong" interpretation of opaque items, which would have conflicted with the familiar meanings associated to them. Converging evidence for this proposal was also reported for Italian derived-words (Amenta et al., 2015). In this work, opaque derived words that also allow a "transparent reading" (e.g., *gallone*, which means *gallon* but can also be read as *gallo+one*, i.e. *big rooster*) were presented within sentence contexts that elicited either interpretation. Fixation times were evaluated during reading using an eye-tracker. Results showed that accessing the word stem (as indexed by stem-frequency effects) had an opposite effect depending on the context: within sentences eliciting an opaque reading of the derived word target (*gallone* as *gallon*), the unrelated stem had a negative impact on processing, leading to longer reading times; on the other hand, sentences eliciting a transparent reading of the target (*gallone* as *big rooster*) caused stem access to boost reading times. These pieces of evidence support the idea that transparency effects crucially build on meaning-composition processes and, more generally, show that slight differences in task demands or experimental manipulation can make the semantic impact in word processing more or less evident (even in masked-priming paradigms; see, e.g., Marelli et al., 2013).

Putting Things Together: Modeling the Semantic Side of Morphological Processing

Taken together, the various experimental studies seem to point out that the inconsistent semantic impact in complex-word processing may depend on the way such semantic impact has been operationalized and assessed. How hence to characterize such semantic aspects? Where one can obtain precise quantitative estimates concerning the semantic side of morphological processing? A principled solution could be found by relying on computational modelling (Amenta et al., 2020).

Distributional semantics (e.g., Landauer & Dumais, 1997), in particular, provides a promising tool to address the present issue. A very popular approach in linguistics and cognitive science (Günther, Rinaldi et al., 2019), distributional semantics relies on the distributional hypothesis (Harris, 1954), stating that the meaning of a word can be approximated by the contexts in which that word appears. Moving from this principle, one can model "context" by collecting word co-occurrences from a reference corpus. The resulting vector, encoding (in a more or less processed way) the textual environment in which a word lives, will end up representing that very word's meaning.[2] Indeed, once semantic vectors are induced from a corpus, it is easy to automatically estimate the degree of semantic relatedness between two words. Although one can, in principle, use such measures as a proxy for semantic transparency (by, for example, computing the proximity between the *dealer* vector and the *deal* vector; Rastle et al., 2000), the resulting estimates will end up suffering from the very issues mentioned above: complex words would not be treated as such, and the relation between a word and its stem would not be qualitatively different that the relation between two independent simple words.

Recent developments in the field have allowed us to go beyond this impasse: compositional distributional semantics (Baroni, 2013; Mitchell & Lapata, 2010) can induce new vector representations by combining known semantic vectors. When applied to morphology, these systems are able to induce quantitatively defined representations for complex-word meanings by relying on a computationally implemented semantic combination process (Lazaridou et al., 2013). Such a flexible approach allows us to automatically compute the meanings of not only familiar transparent words, but also of novel, unfamiliar words (e.g., the meaning of *quickify* can be obtained by combining the distributional representations of *quick* and *-ify*), and it allows a transparent interpretation of familiar opaque words (the meaning of *summer* as "someone who sums" by combining the meanings of *sum* and *-er*). In cognitive science, models for both derived words (Functional Representation of Affixes in Compositional Semantic Space, FRACSS, Marelli & Baroni, 2015) and compounds (Compounding as Abstract Operations in Semantic Space, CAOSS, Marelli et al., 2017) were proposed, aimed at capturing the semantic dynamics triggered during the processing of complex words. Both models are founded on the assumption that, when reading a complex word, a meaning-combination process is always attempted, building on the idea that the very purpose of lexical morphology is generating new meanings.

In FRACSS, affix meaning is conceived as a semantic function (technically a matrix), updating the meaning of the stem it is attached to. The meaning of a complex word is then obtained by multiplying the stem vector by the affix matrix, representing the semantic update that the stem undergoes when combined with an affix: in order to obtain the meaning of *quickify*, the *quick* vector is multiplied by the *-ify* matrix, capturing how the *quick* meaning changes when combined with the *-ify* affix. FRACSS has provided a new framework for understanding semantic effects (or apparent lack thereof) in morphological processing. Indeed, FRACSS estimates capture well some of the behavioral patterns described in the previous sections of this chapter. For example, the priming effect found in masked-priming paradigms (Rastle et al., 2004) are reflected in FRACSS semantic prediction (Marelli & Baroni, 2015), suggesting that the priming effect observed for opaque words (e.g., *corner-corn*) may also reflect a productive meaning-combination process: the opaque prime may facilitate its pseudo-stem because the degraded processing conditions imposed by masked priming would facilitate automatic meaning-composition processes (interpreting *corner* as "someone who grows corn"), inhibiting the access to the familiar, lexicalized derived-word meaning (i.e., the actual meaning of *corner*). Moreover, these very estimates can also replicate cross-linguistic dissociations in priming effect, capturing well the peculiarities of morphological priming in German (Günther, Smolka et al. 2019). FRACSS suggests that these cross-linguistic differences might depend on the different degree of meaning predictability in the two languages, irrespective of the transparency of the individual items. Finally, FRACSS simulations also support the proposal according to which transparency effects need to be framed in a compositional perspective, in order to be comprehensively investigated: FRACSS-based compositional measures of transparency proved to be better predictors of lexical decision latencies than traditionally defined transparency metrics (Marelli & Baroni, 2015).

Similarly to FRACSS, CAOSS models compounds using a matrix-based approach. Differently from FRACSS, CAOSS matrices are not lexically defined (i.e., they do not correspond to specific lexical units) but work as an abstract structure to update the meanings of compound constituents before combining them via summation. CAOSS simulations align with a number of behavioral effects from the word-processing literature. In line with the evidence concerning FRACSS and derived words, CAOSS estimates of semantic transparency are good predictors of behavioral data in a number of tasks (Günther & Marelli, 2019; Günther et al., 2020), unlike traditional transparency metrics. Moreover, effects related to the compound structure (headedness, relational information) are clearly reflected in the CAOSS-induced representations (Marelli et al., 2017), in particular when comparing model simulations to the responses to novel compounds described in Gagné (2001) and Gagné and Shoben (1997). Finally, CAOSS offers a different perspective on the morpheme-interference effects (Günther & Marelli, 2020), showing that rejection times for pseudo-compounds in a lexical decision task are crucially modulated by the ease of semantic integration of the item constituents (as predicted by the model): a pseudo-compound like *radiosauce*, less plausible, will elicit shorter rejection times than a pseudo-compound like *bridgemill*. This effect suggests that the activation of morphemic units is geared towards comprehension, and accessing to morpheme is necessary in order to actively compute the meaning of the complex word (Burani et al., 1999). The morpheme-interference effect might hence be (in part) semantically connoted.

Conclusions

In this chapter, I have presented the long-standing discussion about the role of semantics in the processing of morphologically complex words. Several pieces of evidence have for a long time casted doubt on the existence of substantial meaning-related impact on the activation of morphological information: morphological effects seemed to be relatively independent from semantic ones, and transparency effects were in various studies found to be inconsistent in compound processing and limited in derived-word processing. However, upon closer scrutiny this scenario may have been related to the choice of experimental paradigms and the adopted approach in variable operationalizations. The inconsistency in semantic effects, rather than an indication of a lack of semantic impact, could be interpreted as a call to think differently about meaning in complex words, and in particular about the interplay between semantics and morphology in determining word processing. An attempt to formalize this different perspective is found in models like FRACSS and CAOSS that look at morphological processing as a meaning-combination process. The models developed moving from this assumption have proven successful, explaining existing phenomena, providing new interpretations to well-established effects, and producing better operationalizations of traditional variables. In that, they brought together under a unique explanatory framework the processing of familiar elements and the comprehension of new complex words, pushing the field toward a theoretical perspective that focuses on the very purpose of morphology: generating and denoting new meanings.

Notes

1 In the linguistic literature (e.g., Bisetto & Scalise, 2005), other types of compound structures have been described, like correlational compounds (in which both constituents are considered head of the compound—*singer songwriter*) and exocentric compounds (in which the head is considered to be an external, unexpressed elements; a *pickpocket* is a person who picks pockets). Although there are some results indicating an impact of such structures on word processing (Marelli et al., 2009; Momenian et al., 2020), the phenomenon remains largely uninvestigated in the processing literature and won't be discussed in detail in the present chapter.

2 This semantic-vector approach was also recently adopted within the Naïve Discriminative Learning framework (e.g., Milin et al., 2017; Baayen et al. 2019).

References

Amenta, S., & Crepaldi, D. (2012). Morphological processing as we know it: An analytical review of morphological effects in visual word identification. *Frontiers in Psychology*, 3, 232. doi:10.3389/fpsyg.2012.00232.

Amenta, S., Günther, F., & Marelli, M. (2020). A (distributional) semantic perspective on the processing of morphologically complex words. *The Mental Lexicon*, 15(1), 62–78. doi:10.1075/ml.00014.ame.

Amenta, S., Marelli, M., & Crepaldi, D. (2015). The fruitless effort of growing a fruitless tree: Early morpho-orthographic and morpho-semantic effects in sentence reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 41(5), 1587–1596. doi:10.1037/xlm0000104.

Baayen, R. H., Chuang, Y. Y., Shafaei-Bajestan, E., & Blevins, J. P. (2019). The discriminative lexicon: A unified computational model for the lexicon and lexical processing in comprehension and production grounded not in (de) composition but in linear discriminative learning. *Complexity*, 2019(1): 1–32. doi:10.1155/2019/4895891.

Baroni, M. (2013). Composition in distributional semantics. *Language and Linguistics Compass*, 7(10), 511–522. doi:10.1111/lnc3.12050.

Bertram, R., Baayen, R. H., & Schreuder, R. (2000). Effects of family size for complex words. *Journal of Memory and Language*, 42(3), 390–405. doi:10.1006/jmla.1999.2681.

Bisetto, A., & Scalise, S. (2005). The classification of compounds. *Lingue e linguaggio*, 4(2), 319–332. https://citeseerx.ist.psu.edu/showciting?cid=4419910.

Burani, C., Dovetto, F. M., Spuntarelli, A., & Thornton, A. M. (1999). Morpholexical access and naming: The semantic interpretability of new root–suffix combinations. *Brain and Language*, 68*(*1–2), 333–339. doi:10.1006/brln.1999.2073.

Bloomfield, L. (1933). *Language*. New York: Henry Holt.

Crepaldi, D., Rastle, K., Davis, C. J., & Lupker, S. J. (2013). Seeing stems everywhere: Position-independent identification of stem morphemes. *Journal of Experimental Psychology: Human Perception and Performance*, 39(2), 510–525. doi:10.1037/a0029713.

Davis, M. H., & Rastle, K. (2010). Form and meaning in early morphological processing: Comment on Feldman, O'Connor, and Moscoso del Prado Martín (2009). *Psychonomic Bulletin & Review*, 17*(*5), 749–755. doi:10.3758/PBR.17.5.749.

De Jong, N. H., Schreuder, R., & Baayen, R. H. (2000). The morphological family size effect and morphology. *Language and Cognitive Processes*, 15(4–5), 329–365. doi:10.1080/01690960050119625.

Feldman, L. B. (2000). Are morphological effects distinguishable from the effects of shared meaning and shared form? J*ournal of Experimental Psychology: Learning, Memory, and Cognition*, 26(6), 1431–1444. doi:10.1037//0278-7393.26.6.1431.

Feldman , L. B., Milin, P., Cho, K. W., Moscoso del Prado Martín, F., & O'Connor, P. A. (2015). Must analysis of meaning follow analysis of form? A time course analysis. *Frontiers in Human Neuroscience*, 9, 111. doi:10.3389/fnhum.2015.00111.

Feldman, L. B., O'Connor, P. A., & Moscoso del Prado Martín, F. (2009). Early morphological processing is morphosemantic and not simply morpho-orthographic: A violation of form-then-meaning accounts of word recognition. *Psychonomic Bulletin & Review*, 16(4), 684–691. doi:10.3758/PBR.16.4.684.

Feldman, L. B., & Soltano, E. G. (1999). Morphological priming: The role of prime duration, semantic transparency, and affix position. *Brain and Language*, 68(1–2), 33–39. doi:10.1006/brln.1999.2077.

Fiorentino, R., & Fund-Reznicek, E. (2009). Masked morphological priming of compound constituents. *The Mental Lexicon*, 4(2), 159–193. doi:10.1075/ml.4.2.01fio.

Forster, K. I. (1998). The pros and cons of masked priming. *Journal of Psycholinguistic Research*, 27(2), 203–233. doi:10.1023/A:1023202116609.

Gagné, C. L. (2001). Relation and lexical priming during the interpretation of noun–noun combinations. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 27(1), 236–254. doi:10.1037//0278-7393.27.1.236.

Gagné, C. L., & Shoben, E. J. (1997). Influence of thematic relations on the comprehension of modifier–noun combinations. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 23(1), 71–87. doi:10.1037/0278-7393.23.1.71.

Gagné, C. L., Spalding, T. L., Figueredo, L., & Mullaly, A. C. (2009). Does snow man prime plastic snow? The effect of constituent position in using relational information during the interpretation of modifier-noun phrases. *The Mental Lexicon*, 4(1), 41–76. doi:10.1075/ml.4.1.03gag.

Guevara, E., & Scalise, S. (2009). Searching for universals in compounding. In S. Scalise, E. Magni, & A. Bisetto (Eds.), *Universals of language today* (pp. 101–128). Dordrecht: Springer.

Günther, F., & Marelli, M. (2019). Enter sandman: Compound processing and semantic transparency in a compositional perspective. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 45(10), 1872–1882. doi:10.1037/xlm0000677.

Günther, F., & Marelli, M. (2020). Trying to make it work: Compositional effects in the processing of compound "nonwords." *Quarterly Journal of Experimental Psychology*, 73(7), 1082–1091. doi:10.1177/1747021820902019.

Günther, F., Marelli, M., & Bölte, J. (2020). Semantic transparency effects in German compounds: A large dataset and multiple-task investigation. *Behavior Research Methods*, 52, 1208–1224. doi:10.3758/s13428-019-01311-4.

Günther, F., Petilli, M. A., & Marelli, M. (2020). Semantic transparency is not invisibility: A computational model of perceptually-grounded conceptual combination in word processing. *Journal of Memory and Language*, 112, 104104. doi:10.1016/j.jml.2020.104104.

Günther, F., Rinaldi, L., & Marelli, M. (2019). Vector-space models of semantic representation from a cognitive perspective: A discussion of common misconceptions. *Perspectives on Psychological Science*, 14(6), 1006–1033. doi:10.1177/1745691619861372.

Günther, F., Smolka, E., & Marelli, M. (2019). "Understanding" differs between English and German: Capturing systematic language differences of complex words. *Cortex*, 116, 168–175. doi:10.1016/j.cortex.2018.09.007.

Harris, Z. S. (1954). Distributional structure. *Word*, 10(2–3), 146–162. doi:10.1080/00437956.1954.11659520.

Hasenäcker, J., Solaja, O., & Crepaldi, D. (2020). Food in the corner and money in the cashews: Semantic activation of embedded stems in the presence or absence of a morphological structure. *Psychonomic Bulletin & Review*, 27(1), 155–161. doi:10.3758/s13423-019-01664-z.

Hockett, C. F. (1958). *A course in modern linguistics*. New York: The Macmillan Company.

Ji, H., Gagné, C. L., & Spalding, T. L. (2011). Benefits and costs of lexical decomposition and semantic integration during the processing of transparent and opaque English compounds. *Journal of Memory and Language*, 65(4), 406–430. doi:10.1016/j.jml.2011.07.003.

Kuperman, V., Bertram, R., & Baayen, R. H. (2008). Morphological dynamics in compound processing. *Language and Cognitive Processes*, 23(7–8), 1089–1132. doi:10.1080/01690960802193688.

Landauer, T. K., & Dumais, S. T. (1997). A solution to Plato's problem: The latent semantic analysis theory of acquisition, induction, and representation of knowledge. *Psychological Review*, 104(2), 211–240. doi:10.1037/0033-295X.104.2.211.

Lazaridou, A., Marelli, M., Zamparelli, R., & Baroni, M. (2013). Compositional-ly derived representations of morphologically complex words in distributional semantics. In *Proceedings of the 51st Annual Meeting of the Association for Computational Linguistics (Volume 1: Long Papers)* (pp. 1517–1526). Sofia: Association for Computational Linguistics

Libben, G. (1998). Semantic transparency in the processing of compounds: Consequences for representation, processing, and impairment. *Brain and Language*, 61(1), 30–44. doi:10.1006/brln.1997.1876.

Libben, G., Gibson, M., Yoon, Y. B., & Sandra, D. (2003). Compound fracture: The role of semantic transparency and morphological headedness. *Brain and Language*, 84(1), 50–64. doi:10.1016/s0093-934x(02)00520-5.

Longtin, C. M., & Meunier, F. (2005). Morphological decomposition in early visual word processing. *Journal of Memory and Language*, 53(1), 26–41. doi:10.1016/j.jml.2005.02.008.

Longtin, C. M., Segui, J., & Hallé, P. A. (2003). Morphological priming without morphological relationship. *Language and Cognitive Processes*, 18(3), 313–334. doi:10.1080/01690960244000036.

Marelli, M., Amenta, S., Morone, E. A., & Crepaldi, D. (2013). Meaning is in the beholder's eye: Morpho-semantic effects in masked priming. *Psychonomic Bulletin & Review*, 20 (3), 534–541. doi:10.3758/s13423-012-0363-2.

Marelli, M., & Baroni, M. (2015). Affixation in semantic space: Modeling morpheme meanings with compositional distributional semantics. *Psychological Review*, 122(3), 485–515. doi:10.1037/a0039267.

Marelli, M., Crepaldi, D., & Luzzatti, C. (2009). Head position and the mental representation of nominal compounds: A constituent priming study in Italian. *The Mental Lexicon*, 4(3), 430–454. doi:10.1075/ml.4.3.05mar.

Marelli, M., Dinu, G., Zamparelli, R., & Baroni, M. (2015). Picking buttercups and eating butter cups: Spelling alternations, semantic relatedness, and their consequences for compound processing. *Applied Psycholinguistics*, 36(6), 1421–1439. doi:10.1017/S0142716414000332.

Marelli, M., Gagné, C. L., & Spalding, T. L. (2017). Compounding as Abstract Operation in Semantic Space: Investigating relational effects through a large-scale, data-driven computational model. *Cognition*, 166, 207–224. doi:10.1016/j.cognition.2017.05.026.

Marelli, M., & Luzzatti, C. (2012). Frequency effects in the processing of Italian nominal compounds: Modulation of headedness and semantic transparency. *Journal of Memory and Language*, 66(4), 644–664. doi:10.1016/j.jml.2012.01.003.

Marelli, M., Traficante, D., & Burani, C. (2020). Reading morphologically complex words: Experimental evidence and learning models. In V. Pirelli, I. Plag, and W. Dressler (Eds.), *Word knowledge and word usage* (pp. 553–592). Berlin: De Gruyter.

Marslen-Wilson, W. D., Bozic, M., & Randall, B. (2008). Early decomposition in visual word recognition: Dissociating morphology, form, and meaning. *Language and Cognitive Processes*, 23, 394–421. doi:10.1080/01690960701588004.

Marslen-Wilson, W., Tyler, L. K., Waksler, R., & Older, L. (1994). Morphology and meaning in the English mental lexicon. *Psychological Review*, 101(1), 3–33. doi:10.1037/0033-295X.101.1.3.

Milin, P., Feldman, L. B., Ramscar, M., Hendrix, P., & Baayen, R. H. (2017). Discrimination in lexical decision. *PLoS ONE*, 12(2), e0171935. doi:10.1371/journal.pone.0171935.

Mitchell, J., & Lapata, M. (2010). Composition in distributional models of semantics. Cognitive Science, 34(8), 1388–1429. doi:10.1111/j.1551-6709.2010.01106.x.

Momenian, M., Cham, S. K., Mohammad Amini, J., Radman, N., & Weekes, B. (2020). Capturing the effects of semantic transparency in word recognition: A cross-linguistic study on Cantonese and Persian. *Language, Cognition and Neuroscience*, 36(12), 612–624. doi:10.1080/23273798.2020.186287.

Moscoso del Prado Martín, F., Deutsch, A., Frost, R., Schreuder, R., De Jong, N. H., & Baayen, R. H. (2005). Changing places: A cross-language perspective on frequency and family size in Hebrew and Dutch. *Journal of Memory and Language*, 53(4), 496–512. doi:10.1016/j.jml.2005.07.003.

Rastle, K., & Davis, M. H. (2008). Morphological decomposition based on the analysis of orthography. *Language and Cognitive Processes*, 23(7–8), 942–971. doi:10.1080/01690960802069730.

Rastle, K., Davis, M. H., Marslen-Wilson, W. D., & Tyler, L. K. (2000). Morphological and semantic effects in visual word recognition: A time-course study. *Language and Cognitive Processes*, 15(4–5), 507–537. doi:10.1080/01690960050119689.

Rastle, K., Davis, M. H., & New, B. (2004). The broth in my brother's brothel: Morpho-orthographic segmentation in visual word recognition. *Psychonomic Bulletin & Review*, 11 (6), 1090–1098. doi:10.3758/BF03196742.

Rueckl, J. G., & Aicher, K. A. (2008). Are CORNER and BROTHER morphologically complex? Not in the long term. *Language and Cognitive Processes*, 23(7–8), 972–1001. doi:10.1080/01690960802211027.

Sandra, D. (1990). On the representation and processing of compound words: Automatic access to constituent morphemes does not occur. *The Quarterly Journal of Experimental Psychology Section A*, 42(3), 529–567. doi:10.1080/14640749008401236.

Schäfer, M., & Bell, M. J. (2020). Constituent polysemy and interpretational diversity in attested English novel compounds. *The Mental Lexicon*, 15(1), 42–61. doi:10.1075/ml.00013.sch.

Schmidtke, D., Kuperman, V., Gagné, C. L., & Spalding, T. L. (2016). Competition between conceptual relations affects compound recognition: The role of entropy. *Psychonomic Bulletin & Review*, 23(2), 556–570. doi:10.3758/s13423-015-0926-0.

Schreuder, R., & Baayen, R. H. (1997). How complex simplex words can be. *Journal of Memory and Language*, 37(1), 118–139. doi:10.1006/jmla.1997.2510.

Shoolman, N., & Andrews, S. (2003). Racehorses, reindeer, and sparrows: Using masked priming to investigate morphological influences on compound word identification. In S. Kinoshita and S. J. Lupker (Eds.), *Masked priming: The state of the art* (pp. 241–278). New York: Psychology Press.

Smolka, E., Komlòsi, S., & Roesler, F. (2009). When semantics means less than morphology: The processing of German prefixed verbs. *Language and Cognitive Processes*, 24(3), 337–375. doi:10.1080/01690960802075497.

Smolka, E., Preller, K. H., & Eulitz, C. (2014). "Verstehen" ("understand") primes "stehen" ("stand"): Morphological structure overrides semantic compositionality in the lexical representation of German complex verbs. *Journal of Memory and Language*, 72, 16–36. doi:10.1016/j.jml.2013.12.002.

Taft, M., & Forster, K. I. (1976). Lexical storage and retrieval of polymorphemic and polysyllabic words. *Journal of Verbal Learning and Verbal Behavior*, 15(6), 607–620. doi:10.1016/0022-5371(76)90054-2.

Zwitserlood, P. (1994). The role of semantic transparency in the processing and representation of Dutch compounds. *Language and Cognitive Processes*, 9(3), 341–368. doi:10.1080/01690969408402123.

6

SPEECH PRODUCTION

Where Does Morphology Fit?

Benjamin V. Tucker and Fabian Tomaschek

Introduction[1]

Theories and models of speech production do not generally deal with morphology. While certain models have a morphological subcomponent, others avoid assumptions about morphological processes altogether. An understanding of the entire process of speech production is necessary to understand and investigate the function of morphology and its effects on speech production.

In this chapter, we briefly describe the cognitive and kinematic processes involved in speech production. We then discuss methods and models used to explore speech production and morphology. We conclude with a brief discussion of some of the major themes and directions for future work on this topic. Our goal is not to provide a comprehensive review of these topics. Instead, we aim to provide an overview of some of the major themes in morphological research that we believe are relevant from a speech-production perspective. We hope that this chapter can be used as a starting point for researchers interested in learning more about morphophonetic (morphology and speech production) interactions.

As a crucial first step, we provide a brief explanation of what we mean when we use the terms "morphology" and "morphological structure." We define morphology as a systematic combination of sounds and meanings. Morphological structure then is a reference to how these combinations are cognitively stored and represented. We make no claims about how these combinations emerge and about the nature of the representations. There is a vast literature to explore for those interested in these topics (e.g., Dell et al., 1999; Fromkin, 1971; Hay and Baayen, 2005). With a simple, likely incomplete, definition for morphology we describe the processes involved in speech production.

DOI: 10.4324/9781003159759-6

What Is Speech Production?

In this section, we describe the major steps that need to occur for a speaker to produce speech. This isn't the only way to conceptualize speech production; some of the research cited below conceptualizes this process similarly and in more detail than we do here.

As illustrated in Figure 6.1, we have divided speech production into three phases, following the subdivision in the speech production literature. The three major speech production phases are: (1) cognitive preparation; (2) motor preparation; and (3) motor execution. We elaborate these stages for the utterance: *Pizza is my favorite meal.*

First, the speaker needs to decide that they want to express their preference for *pizza*. This stage of cognitive preparation includes the activation of semantic concepts, lexical choices, and structural choices. Following this stage, the speaker prepares the sequence of motor articulations related to the utterance as part of the motor preparation stage as illustrated in Figure 6.1(b). For example, *pizza* requires a bilabial stop gesture for /p/ (1), a high-front tongue position and voicing for /i/ (2), an alveolar tongue position which creates a complete closure for /t/ followed quickly by a partial closure for /s/ with no voicing (3), which is followed by a low-back tongue position with voicing for /ə/ (4). All of these events have to occur in addition to planning the flow of air out of the lungs into the laryngeal process exciting the vocal folds and flowing into the oral cavity (A).

The prepared motor programs are then executed as part of the motor execution stage. This produces a sequence of articulatory events that generate an acoustic

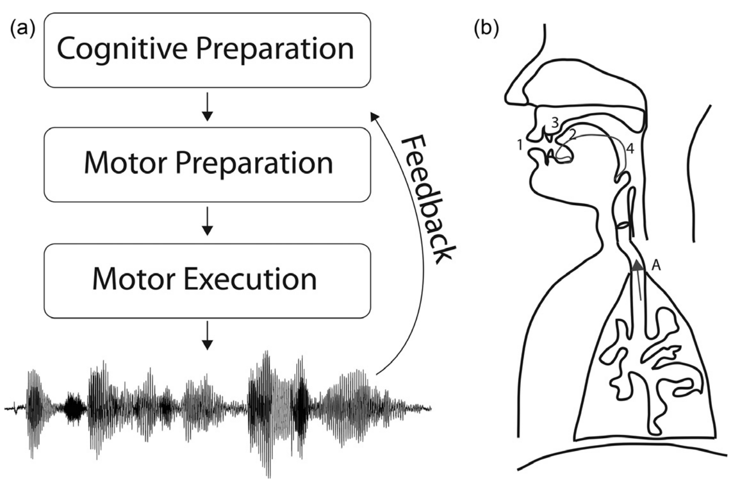

FIGURE 6.1. (a) Summary diagram of the major stages of speech production; and (b) Midsagittal of the full speech production mechanism; Air pushed out of the lungs (A): articulators are moving during the production of the word "pizza" (1–4).

signal to be perceived by the intended audience. While speakers are able to actively influence certain aspects of these stages (e.g., Lindblom, 1990), what we have described as a process largely happens subconsciously. Furthermore, while the stages are described sequentially they could easily occur in parallel. And we have one final note about the feedback arrow in our diagram of speech production (Figure 6.1(a)). Often when a speaker detects an error in their own speech, a repair quickly follows. This is a result of the fact that speakers are constantly monitoring their own speech.

Where does morphology fit? Morphological processes comprise the concatenation of bits of meaning often classified as compounding, derivation, and inflection. Most researchers agree that these morphological processes fall into the cognitive preparation phase. However, in many studies of speech production and morphology, inferences about the cognitive preparation phase are made on the basis of the data that comes from the result of the motor preparation and execution phases. In addition, most cognitive models don't concern themselves with predictions at these levels. It is therefore important to have a basic understanding of all the phases of speech production even if the focus is on morphology.

Morphology and Speech Production

The earliest evidence for a connection between morphology and speech production is derived from speech production errors. For example, in *slicely thinned* for *thinly sliced* (Stemberger, 1985), stems are exchanged whereas the suffixes remain in their "correct place." The utterance *he's sort of a commuCRAT demoNIST* from Fromkin (1971) also illustrates this type of speech error. Further evidence is provided by aphasic patients for whom speech errors depend on different kinds of morphological processes and the morphological complexity of words (Miceli and Caramazza, 1988).

Word-reading and picture-naming experiments provide additional evidence that morphological complexity plays a role during speech production. For example, the amount of time it takes to name a word (latency) systematically differs between morphologically complex and simple words (e.g., Roelofs, 1997a). Also, latencies have been found to depend on semantic transparency (Zwitserlood et al., 2002) and the frequency of morphemes in morphologically complex words (Bien et al., 2011). These studies show that morphological complexity interacts with the timing of cognitive preparation and thus the speed with which a word is articulated. To investigate how morphological complexity interacts with the production process, two kinds of data have been collected: (a) articulatory data where movements of the tongue and the jaw are recorded; and (b) acoustic data.

Articulatory movements are systematically different at morpheme boundaries than within morphemes (Lee-Kim et al., 2012). A frequent target of acoustic investigations are morphemic and non-morphemic speech sounds, and those that can have multiple meanings (such as [s] in *gue-ss, cat-s*, and *walk-s*). These acoustic studies show that the duration of such speech sounds depends on whether they are part of an affix or part of a word (Plag et al., 2017; Seyfarth et al., 2018). Furthermore, free and bound variants of a stem differ acoustically, and listeners can make use of such phonetic cues in perception (Blazej and Cohen-Goldberg, 2015; Kemps et al., 2004). Crucially, such effects are not restricted to the morphological level, but also expand to the lemma level such that there are systematic acoustic differences between verbs and nouns (Lohmann, 2018; Lohmann and Conwell, 2020).

One interpretation of these findings, comparing morphemic and non-morphemic speech sounds, is that the interaction between morphology and speech production might be categorical. Research investigating other morphological phenomena (e.g., stress patterns, irregulars, paradigms, gemination, resyllabification, etc.) has used gradient measures that assess the strength of the representation in the lexicon and its effects on speech production. These measures include, among others, word frequency (Tomaschek et al., 2018), a word's probability in its inflectional paradigm (Cohen, 2015; Kuperman et al., 2007; Tomaschek et al., 2021), sublexical relations (Arndt-Lappe, 2011), paradigmatic family size (Bell et al., 2021), measures of morphological segmentability and semantic specificity (Bell and Plag, 2012), and measures of certainty/uncertainty from neural networks (e.g., Tomaschek et al., 2019; Tucker et al., 2019).

Models of Speech Production

Understanding models of speech production is important to identifying the influence of morphology on speech and predicting how morphology interacts with the articulatory system. We start with cognitive preparation models—dividing these into early schematic psycholinguistic models and the subsequent computational psycholinguistic models. We briefly touch on phonetic models and conclude this section by discussing combined psycholinguistic and phonetic models. Other summaries of relevant research and models can be found in the individual works and in research summaries by Stemberger (2017), Tucker (2019), and Zwitserlood (2018).

Cognitive Preparation I: Schematic Psycholinguistic Models

Early schematic models are similar to the description of the process of speech production that we have described in the introduction. These models codify the main levels of speech production and use a schema to make predictions. The schematic models largely utilized speech error data for motivating the structure of their models (Fromkin, 1988). Speech errors can be segmental, syllabic, morphological, syntactic, and semantic in nature, often occurring as additions, substitutions, omissions, deletions, transpositions, or blends (e.g. Dell, 1986; Fromkin, 1971).

The following serial models derive speech production by going from one level to the next in a forward-feeding manner, generally not allowing for parallel processing. The early schematic model by Fromkin (1971) consists of five sequential levels: (a) meaning; (b) syntactic structure; (c) intonation and primary stress; (d) lexical selection; and (e) morphophonemic rules. Accordingly, to produce the utterance *Pizza is my favorite meal* the speaker selects the intended semantics, then creates a syntactic structure for the utterance, then generates the intonation and stress patterns, subsequently selects the appropriate lexical items, and applies morphophonological rules. Finally, the motor preparation and execution stages result in the production of the intended utterance.

The model by Garrett (1988) contains three basic stages, similar to the above description in the introduction: (a) conceptual; (b) formulation; and (c) articulation. The second, formulation stage is further divided into three additional substages: (i) functional; (ii) positional; and (iii) sound. In this model, to produce the *Pizza* sentence a speaker would first conceptualize the intention or idea of the utterance. This is followed by the formulation stage where the syntactic structures are selected and then content words are selected. Then phonological forms are mapped to the syntactic structure or frame. Once the syntactic structure is generated, the function words and inflectional morphological affixes are added to the utterance at the positional level. In Garrett's (1988) model, inflectional morphology occurs at the positional level but the derivational morphology occurs at the word-selection level. Finally, a linear sequence of phonological features is created by applying phonological rules allowing sounds to be deleted and modified, and this is then followed by the articulation.

Cognitive Preparation II: Computational Psycholinguistic Models

More recent psycholinguistic/cognitive models of speech production include computational implementations. These models differ in (a) how they conceptualize word composition and (b) whether different stages of preparation can interact with each other. We describe the role of morphology in these models while taking into account possible interactions between the cognitive preparation stage and the motor stage.

An influential psycholinguistic theory of cognitive preparation is the Theory of Lexical Access (Levelt et al., 1999). This theory focuses on single-word production and is separated into three different levels. The first level is conceptualization, during which lexical concepts are selected. A core process is the weighting of semantic information to select one concept among semantically related concepts, concretely synonyms and hyperonyms. During the second or lemma level, the selected lexical concept activates the lemma. Morphological inflectional is distributed across different levels. Inflectional features, such as number, tense, and aspect, are activated during the lemma level. These features are then used during morphological encoding to select morphemes.

Another aspect related to morphology is that the selection process differs between regular and irregular complex word forms. When a word is irregular (e.g., "went"), its irregular morpheme is extracted directly from the lexicon. When a word is regular (e.g., "walked"), its inflectional features select sublexical units such as stems ("walk") and affixes ("ed") during morphological encoding. Finally, compounding and derivational processes are assumed to originate at the lemma level, during which stem morphemes are obtained and used to construct words (Levelt et al., 1999).

Once morphemes are selected, they are used to activate phonemes for which a syllabic structure is calculated. High-frequency syllables are obtained from a syllabary, which contains prefabricated motor programs. Low-frequency syllables have to be generated. At each level, multiple units may compete for activation. The unit with the highest activation is selected and validated.

Picture- and word-naming experiments as well as neuroimaging studies (among many others, Jescheniak and Levelt, 1994; Levelt and Wheeldon, 1994; Roelofs, 1997a) provide supporting evidence for this theory. These studies investigated the order in which grammatical, morphological, and phonological information is processed during cognitive preparation. This is accomplished by means of priming paradigms in which a primed stimulus is presented before a target word that has to be articulated. The perception of a prime activates semantic, morphological, and phonological information, which may or may not be shared with the target word. Shared pieces of information pre-activate the target, which reduces the target's preparation time, which is reflected by faster naming latencies of the target word.

Roelofs (1997a) investigated to what extent a free morpheme in Dutch such as *bij* [bɑɪ] "at"' primed dimorphemic words such as *bijrol* "supporting role," in which [bɑɪ] constituted a morpheme, and monomorphemic words such as *bijbel* "Bible," in which [bɑɪ] was a simple phonological sequence. He found that naming latencies were faster for morphologically complex words in which the prime constituted a morpheme than they were for monomorphemic words in which the prime was simply a phonological sequence in a monomorphemic word (Roelofs, 1998). He interpreted this result to indicate that morphological construction takes place before phonological construction. For readers who are interested in issues of lexical structure and access, we point to, among others, the study by Caramazza et al. (2001).

The Theory of Lexical Access was implemented computationally as Weaver++ (Roelofs, 1997b), an activation-spreading, feed-forward model with three levels: (1) the lemma and its inflectional features select morphemes during morphological encoding; (2) these are phonologically encoded; and (3) they are then phonetically encoded. Once higher-level units select lower-level units, information from the higher level is deleted and ignored in subsequent processes. While the model excludes interactions between different levels, and therefore does not predict effects of higher-level information on articulation, it allows for predictions about the timing of cognitive preparation as reflected by naming latencies. This is accomplished by taking into account differences in the structural complexity of words at the morphological and syllabic levels. In addition, the model accounts for different degrees of experience with each of these levels, as typically gauged by frequency of occurrence.

The Spreading-Activation Theory of Retrieval (Dell, 1986) is similar to Weaver++ in terms of the different levels and their sequencing. As the model was designed to produce sentences, it incorporated syntactic rules that applied during the conceptualization level. Together with the lemma, syntactical rules generated morphemes that were concatenated by means of morphological rules. Subsequently, phonemes were activated and concatenated using phonological rules.

Besides producing utterances, the model should also be capable of producing utterances with errors that are equivalent to observed speech errors. This was accomplished by allowing bi-directional activation spreading (hence the model's name) from higher to lower and from lower to higher levels. Simultaneously, neighboring units at both levels can be activated. In this way, the model can explain phonological and morphological exchanges such as *slicely thinned*.

The initial model by Dell may be considered a hybrid between a multi-layer neural network and rule-based processes. Data from aphasia and language impairment has been used to refine the model (see Dell et al., 2007). In the latest iteration of the model, no intermediate application of grammatical rules is postulated. Thus, morphological structures emerge through the training of the network. This refinement favors whole-word representations, which might be interpreted as ignoring morphological structure and morphological relations among words. However, the semantic-phonological model allows activations to spread from the conceptual level via the word-form level until phonological preparation. This allows phonological activation to co-vary with lexeme information. Furthermore, the model allows neighboring units of any kind—semantic, lemma, phonological—to be co-activated. Through this interaction, it is likely that activation patterns occur in the model that converge on systematic form–meaning pairings. Accordingly, it is possible to model effects of morphological complexity or paradigmatic structure even without an intermediate level at which words are decomposed into morphemes.

Weaver++ predicts frequency effects associated with lemma frequency, morpheme frequency, and syllable frequency, while in the semantic-phonological model word frequency affects activation at all levels (Kittredge et al., 2008). Effects that are accounted for by Weaver++ at the morpheme level might therefore arise through an interaction between the phonological level and lexeme level in the semantic-phonological model. In Weaver++ and the spreading-activation model, the mapping of meaning on some kind of form is accomplished by activating sub-word units. Typically, the size and form of these units are based on formal theories of morphology.

Similarly to the phonological-semantic model, this approach is also abandoned in Baayen et al. (2019)'s Linear Discriminative Learning model (LDL), which is based on notions from discrimination learning (Ramscar et al., 2010). In contrast to the semantic-phonological model, semantics in LDL are not hand-crafted but are based on the computational training of a high-dimensional semantic vector space. A semantic vector space is obtained by training a neural network to learn how informative different word forms are about one another on the basis of their co-occurrences (see also Landauer and Dumais, 2008). For example, because they occur frequently in a similar context, the word *pepperoni* is informative about a *pizza*, but less so about an *omelette*. In LDL, the learning of the semantic vector spaces is accomplished through discriminative learning.

In LDL, production is accomplished by mapping the semantic vector space onto a form vector space. A form vector space connects word forms to n-grams—that is, sequences of phones or letters with the length of two or three. In this way, it defines which word forms consist of which n-grams without any assumptions about the size of the segmental chunk. In this way, the model does not have any predefined morphemes. Similar to the semantic-phonological model, morphemic-like entities emerge where information from the semantic space and the form space converge onto one another.

Weaver++, the semantic-phonological model, and LDL differ fundamentally in (a) how they treat sub-word relations; (b) how higher-level information is passed down toward lower levels; and (c) how morphology is (or is not) incorporated and how it may or may not affect speech production. All three models make predictions about the degree of activation of phone sequences of different sizes. In Weaver++, high-frequency syllables are pre-activated in contrast to low-frequency syllables. In the semantic-phonological model, the activation of individual phones varies with higher-level activation and word frequency. In LDL, n-gram sequences vary in their path weights, which depend on the weights in the semantic vectors for a word. However, none of the models make actual predictions about articulatory processes or the acoustic outcomes. Rather, these are outsourced to models of phonetic production (motor preparation and execution), which we briefly discuss in the following section.

Phonetic Models: Motor Preparation and Motor Execution

Models of motor preparation and motor execution are concerned with questions of how the phone sequence that has been prepared is transformed into a sequence of timed motor commands and then executed. These models rely on extensive research using acoustic recordings, electromagnetic articulography, electromyography, and electropalatography.

Some of these models are Articulatory Phonology (Goldstein and Fowler, 2003, and many others), the Task Dynamic Approach (Saltzman and Munhall, 1989), and the 3 Components / Extrinsic Timing model (3C/XT) (Turk and Shattuck-Hufnagel, 2020). These models of motor preparation differ in how they conceptualize (a) articulatory gestures, that is the coordinated movements of articulators to produce phones; and (b) the timing of articulatory gestures. All of these models account for timing differences during articulation. All models accept that articulatory coordination is not absolute, but rather depends on timing in general and that it is relative to prosodic domains. For example, phonetic effects associated with morphology can potentially be explained to result from timing changes in relation to prosodic domains (see Cho, 2016 for a review).

As we have discussed above, the cognitive preparation may vary in its timing. These timing differences correlate with the speed of articulation (e.g., Bell et al., 2009). In terms of modeling, changes in movement velocity during motor preparation might be predicted by means of different morphological functions in Weaver++; with different activation of phonemes from the semantic level in the semantic-phonological model; or in relation to path weights in LDL due to the activation of morphosemantic information.

Motor preparation models are very powerful in terms of their predictions about potential timing differences during speech production. Unfortunately, they do not explain motor execution. A few recent models are Vocal Tract Lab (Birkholz et al., 2006), Tube Talker (Story, 2005), and 3D mesh-models (Gully and Tucker, 2019). These models modify the articulatory properties of the vocal tract by using gestural scores or modifications to the vocal tract area function to generate acoustic output.

Speech production is a dynamic process in which motor execution is not only driven by motor preparation, but also modulated by somatosensory and acoustic feedback in case of speech errors. The Directions Into Velocities of Articulators model (DIVA; Guenther, 2016) presents a framework that accounts for feedback while modeling both motor preparation and motor execution. The motor execution models do not account for how articulatory coordination is accomplished. Models such as ArtiSynth (Lloyd et al., 2012) or GEPPETTO (Perrier et al., 2006) are biomechanical models that do exactly this, but do not yet produce an acoustic signal.

Combined Models: From Cognitive to Execution

Lastly, recent models that we are calling *combined models* (a small subset of the total number) include all three stages of speech production. These combined models can then be used to make predictions about morphology at the level of acoustics and articulation. Hickok (2012) proposes a model that essentially takes existing cognitive preparation models and motor preparation and motor execution models and combines them. The hierarchical state feedback control (HSFC) theoretical framework (Hickok, 2012) conceptually takes notions from WEAVER++ and DIVA and combines them. The semantic-lexical auditory-motor model (SLAM; Walker and Hickok, 2016) builds on Foygel and Dell (2000) and proposes a revised model. In SLAM, phonological sequences are selected by means of auditory as well as by means of motor activations. Crucially, in the non-combined models, assumptions have to be made about speech production to make predictions about the morphological effects on speech, while combined models can make direct predictions.

Discussion

Our aim was to illustrate that models of speech production, and how they conceptualize the processes of cognitive preparation, motor preparation, and motor execution, are important for understanding morphology, making accurate predictions about the effects of morphology on speech production, and investigating speech production by means of morphology. The critical point is that most models focus on their domain-specific processes—cognitive preparation, motor preparation, motor execution—and ignore interactions between different stages. It thus follows that models that combine different or even all stages of speech production are important for making accurate predictions about speech production.

In the remainder of the discussion, we focus on three themes that emerge from the previous description: (1) the role of morphology in models of speech production; (2) the importance of carefully considering the methods and data in developing theories about and investigating morphology; and (3) the function of computational models in investigating morphology and speech production.

Where Does Morphology Fit in Speech Production?

Word structure can differ due to inflection, derivation, compounding, or even all three together. Therefore, word structure plays an important role in the encoding of semantic information. Psycholinguistic theories agree that the source of different words' structures is located at the cognitive preparation stage; they differ in how they implement the aspects of this stage.

Weaver++ and the spreading-activation model contain levels specifically designated to account for morphological structures and thus morphological processes that are embedded in the hierarchical production process (Dell, 1986; Levelt et al., 1999; Roelofs, 1997b). Regular morphologically complex words are constructed on the basis of inflectional features and discrete sub-word units. This conceptualization about the role of morphology in cognitive preparation has important implications for our assumptions about the structure of the lexicon. From this decompositional perspective, the cognitive preparation stage consists of compositional processes that are based on symbolic units.

By contrast, the phonological-semantic model (Foygel and Dell, 2000) and the Linear Discriminative Learning model (LDL; Baayen et al., 2019) do not have a module specifically dedicated to morphology. However, morphological complexity is an inherent part of the speech production system in LDL. Lexical knowledge can be best thought of as a high-dimensional network in which semantic and sublexical relations are established through learning. As a result, units such as stems or affixes emerge when semantic information and phonological information converge.

Methods and Data

The development of the discussed models and theories has relied on data from speech error corpora, elicited speech errors, word-naming reaction times, pathological speech, and even neuroimaging experiments. This data has been mainly interpreted to indicate a decompositional lexicon. Recently, scholars have started to investigate acoustic and articulatory characteristics of speech that support assumptions of a more gradient lexicon.

One might very easily draw the conclusion that the different approaches resulted in the different theoretical developments, since they produced data with specific characteristics that fed back into the theories and models. It is also true that speech errors support the assumption that speech production is based on a concatenative cognitive preparation process. Naming latencies and neuroimaging experiments highlight the procedural aspects of cognitive preparation. By contrast, acoustic data is inherently variable and thus more likely supports a gradient perspective.

This conclusion does not account for two crucial arguments. The first argument is that all of these methods are important to investigate and understand morphological processes and their effects on speech production, as they provide different insights into the processes. Speech errors allow the researcher to infer levels of abstractions that are involved during speech production. Naming latencies and neuroimaging data provides the researcher with insights into the timing of the cognitive and motor preparation stages. These are important in order to understand the degree to which speech production is a sequential or parallel process.

However, these methods ingeniously stop just before the motor execution stage begins, which is, as we have argued, an essential part of speech production. Without motor execution, no speech is produced. In particular, spoken-word production research needs to expand beyond speech errors and naming latencies, and expand beyond simple measures of duration to other acoustic measures and articulation. Some studies have begun heading in these directions (e.g., Cohen, 2015; Tomaschek et al., 2020). Investigation of morphology in speech production will allow us to investigate interactions between cognitive preparation, motor preparation, and motor execution. Only in this way will we be able to begin to understand what morphological effects result from the timing of cognitive and motor preparation and what effects emerge from other, potentially still unknown sources.

Due to simplifications in experimental designs, typically undertaken to better control the environment, many experiments on morphology have been conducted using single words. We recognize that in many instances the theoretical goals and research goals have been to describe the process for words only. This also holds true for some of the models we discussed. However, humans rarely produce morphologically complex words in isolation. Instead, words are produced in context. Numerous studies show that context matters for speech production (e.g., Tomaschek et al., 2019). This is why future studies need to investigate how morphological processes happen within the context of other words. This call applies to both experimental approaches and modeling approaches.

The second argument is that modern linguistic and psycholinguistic studies use state-of-the art statistical approaches to analyze their data. Researchers should not be satisfied with simple, categorical measures, as they easily lead to the conclusion that cognitive processes are simple and categorical. Only when using complex and gradient measures is it possible to understand the complexity of cognitive processes underlying the production of morphologically complex words. Ideally, these measures should expand beyond words and their direct neighbors and take broader contexts and maybe even other modalities into account.

Modeling

Typically, theories and computational models are developed for one stage of speech production. However, one of the important messages from this chapter is that it may be time to move on from models constrained to one domain and start building more complex, combined models of speech production. Such combined models have great potential to predict and therefore investigate effects of morphology on speech production.

Ideally, these models provide frameworks that allow the researcher to simply remove parts and replace them with new or different parts while keeping other things constant. The combined model proposed by Hickok (2012) is essentially this type of framework. For example, we could have a framework that keeps the motor preparation and execution aspect constant while exchanging the cognitive preparation models. This would allow for comparisons of how morphology is realized in models like Weaver++, LDL, and the semantic-phonological model. We could further modify specific aspects or levels of the cognitive preparation models with areas specific to the morphological structure, and test specific hypotheses. These approaches need researchers to acknowledge other theoretical perspectives and potential explanations of the phenomena they are observing in their data.

When describing our three stages—cognitive preparation, motor preparation, and motor execution—we also briefly mentioned proprioceptive feedback and its role in speech production. The fact that during speech production speakers are constantly listening to themselves and making corrections is an important indicator that perception is occurring. This self-monitoring or self-speech perception further illustrates that it may be beneficial to explore combining models of speech production with models of speech perception/spoken-word recognition. This may cause researchers to consider where and how perception and production interact and at what stages/levels of the process they interact. Specifically, if they interact at the lexical level, where we would expect morphology to occur, then predictions could be made for morphology in both perception and production. One other area in which modality may be further combined would be to consider the similarities between the data and models of speech and writing (as suggested by Fromkin, 1971, among many others).

Conclusion

Speech production is the result of complex cognitive and biomechanical processes. Investigating these processes is the foundation of our understanding of the role that morphological processes play during speech production, and the use of various methods and measures allows us to investigate the dynamics of cognitive processes. Researchers interested in the cognitive processes underlying morphology and who are thus interested in the cognition of speech should not be afraid to expand their theoretical and methodological boundaries. In this way, future researchers can boldly go where no morphologist has gone before.

Note

1 Funding for this work has been provided by the Deutsche Forschungsgemeinschaft (Research Unit FOR2373: Spoken Morphology Project entitled "Articulation of Morphologically Complex Words," BA 3080/3–2).

References

Arndt-Lappe, S. (2011), "Towards an Exemplar-Based Model of Stress in English Noun–Noun Compounds," *Journal of Linguistics* 47 (3), 549–585. doi:10.1017/S0022226711000028.

Baayen, R. H., Chuang, Y.-Y., Shafaei-Bajestan, E., and Blevins, J. P. (2019), "The Discriminative Lexicon: A Unified Computational Model for the Lexicon and Lexical Processing in Comprehension and Production Grounded Not in (De)Composition but in Linear Discriminative Learning," *Complexity* 2019 (1), 1–39. doi:10.1155/2019/4895891.

Bell, A., Brenier, J. M., Gregory, M., Girand, C., and Jurafsky, D. (2009), "Predictability Effects on Durations of Content and Function Words in Conversational English," *Journal of Memory and Language* 60 (1), 92–111. doi:10.1016/j.jml.2008.06.003.

Bell, M. J., Ben Hedia, S., and Plag, I. (2021), "How Morphological Structure Affects Phonetic Realization in English Compound Nouns," *Morphology* 31, 87–120. doi:10.1007/s11525-020-09346-6.

Bell, M. J. and Plag, I. (2012), "Informativeness Is a Determinant of Compound Stress in English," *Journal of Linguistics* 48 (3), 485–520. doi:10.1017/S0022226712000199.

Bien, H., Baayen, R. H., and Levelt, W. J. (2011), "Frequency Effects in the Production of Dutch Deverbal Adjectives and Inflected Verbs," *Language and Cognitive Processes* 26 (4–6), 683–715. doi:10.1080/01690965.2010.511475.

Birkholz, P., Jackel, D., and Kroger, B. J. (2006), "Construction and Control of a Three-Dimensional Vocal Tract Model," in *2006 IEEE International Conference on Acoustics Speech and Signal Processing Proceedings*, Toulouse: IEEE.

Blazej, L. J. and Cohen-Goldberg, A. M. (2015), "Can We Hear Morphological Complexity before Words Are Complex?" *Journal of Experimental Psychology. Human Perception and Performance* 41 (1), 50–68. doi:10.1037/a0038509.

Caramazza, A., Costa, A., Miozzo, M., and Bi, Y. (2001), "The Specific-Word Frequency Effect: Implications for the Representation of Homophones in Speech Production," *Journal of Experimental Psychology: Learning, Memory, and Cognition* 27 (6), 1430–1450. doi:10.1037/0278-7393.27.6.1430.

Cho, T. (2016), "Prosodic Boundary Strengthening in the Phonetics–Prosody Interface," *Language and Linguistics Compass* 10 (3), 120–141. doi:10.1111/lnc3.12178.

Cohen, C. (2015), "Context and Paradigms: Two Patterns of Probabilistic Pronunciation Variation in Russian Agreement Suffixes," *The Mental Lexicon* 10 (3), 313–338. doi:10.1075/ml.10.3.01coh.

Dell, G. S. (1986), "A Spreading-Activation Theory of Retrieval in Sentence Production," *Psychological Review* 93, 283–321. doi:10.1037/0033-295X.93.3.283.

Dell, G. S., Chang, F., and Griffin, Z. M. (1999), "Connectionist Models of Language Production: Lexical Access and Grammatical Encoding," *Cognitive Science* 23 (4), 517–542. doi:10.1016/S0364-0213(99)00014-2.

Dell, G. S., Martin, N., and Schwartz, M. F. (2007), "A Case-Series Test of the Interactive Two-Step Model of Lexical Access: Predicting Word Repetition from Picture Naming," *Journal of Memory and Language* 56 (4), 490–520. doi:10.1016/j.jml.2006.05.007.

Foygel, D. and Dell, G. S. (2000), "Models of Impaired Lexical Access in Speech Production," *Journal of Memory and Language* 43 (2), 182–216. doi:0.1006/jmla.2000.2716.

Fromkin, V. A. (1971), "The Non-Anomalous Nature of Anomalous Utterances," *Language* 47 (1), 27–52. doi:10.2307/412187.

Fromkin, V. A. (1988), "Grammatical Aspects of Speech Errors," in F. J. Newmeyer, ed., *Linguistics: The Cambridge Survey*, Vol. 2, Cambridge: Cambridge University Press, pp. 117–138.

Garrett, M. F. (1988), "Processes in Language Production," in F. J. Newmeyer, ed., *Linguistics: The Cambridge Survey*, Vol. 3, Cambridge: Cambridge University Press, pp. 69–96.

Goldstein, L. and Fowler, C. A. (2003), "Articulatory Phonology: A Phonology for Public Language Use," in N. Schiller and A. Meyer, eds, *Phonetics and Phonology in Language Comprehension and Production: Differences and Similarities*, Berlin: De Gruyter, pp. 159–207.

Guenther, F. H. (2016), *Neural Control of Speech*, Cambridge, MA: MIT Press.

Gully, A. and Tucker, B. V. (2019), "Modeling Voiced Stop Consonants using the 3D Dynamic Digital Waveguide Mesh Vocal Tract Model," in S. Calhoun, P. Escudero, M. Tabain, and P. Warren (eds), *Proceedings of the 19th International Congress of Phonetic Sciences*, Melbourne: International Phonetic Association, pp. 477–481.

Hay, J. B. and Baayen, R. H. (2005), "Shifting Paradigms: Gradient Structure in Morphology," *Trends in Cognitive Sciences* 9 (7), 342–348. doi:10.1016/j.tics.2005.04.002.

Hickok, G. (2012), "Computational Neuroanatomy of Speech Production," *Nature Reviews Neuroscience* 13 (2), 135–145. doi:10.1038/nrn3158.

Jescheniak, J. D. and Levelt, W. J. M. (1994), "Word Frequency Effects in Speech Production: Retrieval of Syntactic Information and of Phonological Form," *Journal of Experimental Psychology: Learning, Memory and Cognition* 20 (4), 824–843. doi:10.1037/0278-7393.20.4.824.

Kemps, R., Ernestus, M., Schreuder, R., and Baayen, H. (2004), "Processing Reduced Word Forms: The Suffix Restoration Effect," *Brain and Language* 90 (1), 117–127. doi:10.1016/S0093-934X(03)00425-5.

Kittredge, A. K., Dell, G. S., Verkuilen, J., and Schwartz, M. F. (2008), "Where Is the Effect of Frequency in Word Production? Insights from Aphasic Picture-Naming Errors," *Cognitive Neuropsychology* 25 (4), 463–492. doi:10.1080/02643290701674851.

Kuperman, V., Bertram, R., and Baayen, R. H. (2007), "Affixal Salience at Large: Morphological Processing of Dutch Suffixes." Manuscript. Nijmegen: Radboud University, 1–26.

Landauer, T. K. and Dumais, S. (2008), "Latent Semantic Analysis," *Scholarpedia* 3 (11), 4356. http://scholarpedia.org/article/Latent_semantic_analysis.

Lee-Kim, S.-I., Davidson, L. and Hwang, S. (2012), "Morphological Effects on the Darkness of English Intervocalic /l/," *Laboratory Phonologya* 4 (2), 475–511. doi:10.1515/lp-2013-0015.

Levelt, W. J. M., Roelofs, A., and Meyer, A. S. (1999), "A Theory of Lexical Access in Speech Production," *Behavioral and Brain Sciences* 22 (1), 1–38. doi:10.1017/s0140525x99001776.

Levelt, W. J. M. and Wheeldon, L. (1994), "Do Speakers Have Access to a Mental Syllabary?" *Cognition* 50 (1–3), 239–269. doi:10.1016/0010-0277(94)90030-2.

Lindblom, B. (1990), "Explaining Phonetic Variation: A Sketch of the H&H Theory," in W. J. Hardcastle and A. Marchal, eds, *Speech Production and Speech Modeling*, Dordrecht: Kluwer, pp. 403–440.

Lloyd, J. E., Stavness, I., and Fels, S. (2012), "ArtiSynth: A Fast Interactive Biomechanical Modeling Toolkit Combining Multibody and Finite Element Simulation," in Y. Payan, ed., *Soft Tissue Biomechanical Modeling for Computer Assisted Surgery*, Berlin: Springer, pp. 355–394.

Lohmann, A. (2018), "Cut (n) and Cut (v) Are Not Homophones: Lemma Frequency Affects the Duration of Noun–Verb Conversion Pairs," *Journal of Linguistics* 54 (4), 753–777. doi:10.1017/S0022226717000378.

Lohmann, A. and Conwell, E. (2020), "Phonetic Effects of Grammatical Category: How Category-Specific Prosodic Phrasing and Lexical Frequency Impact the Duration of Nouns and Verbs," *Journal of Phonetics* 78, 100939. doi:10.1016/j.wocn.2019.100939.

Miceli, G. and Caramazza, A. (1988), "Dissociation of inflectional and derivational morphology," *Brain and Language* 35 (1), 24–65. doi:10.1016/0093-934X(88)90100-9.

Perrier, P., Ma, L., and Payan, Y. (2006), "Modeling the Production of VCV Sequences via the Inversion of a Biomechanical Model of the Tongue," *arXiv:physics*. doi:10.48550/arXiv.physics/0610170.

Plag, I., Homann, J., and Kunter, G. (2017), "Homophony and Morphology: The Acoustics of Word-Final S in English," *Journal of Linguistics* 53 (1), 181–216. doi:10.1017/S0022226715000183.

Ramscar, M., Yarlett, D., Dye, M., Denny, K., and Thorpe, K. (2010), "The Effects of Feature-Label-Order and Their Implications for Symbolic Learning," *Cognitive Science* 34 (6), 909–957. doi:10.1111/j.1551-6709.2009.01092.x.

Roelofs, A. (1997a), "Morpheme Frequency in Speech Production: Testing WEAVER," in G. E. Booij and J. van Marle, eds, *Yearbook of Morphology 1996*, Dordrecht: Springer, pp. 135–154.

Roelofs, A. (1997b), "The WEAVER Model of Word-Form Encoding in Speech Production," *Cognition* 64 (3), 249–284. doi:10.1016/S0010-0277(97)00027-9.

Roelofs, A. (1998), "Rightward Incrementality in Encoding Simple Phrasal Forms in Speech Production: Verb–Particle Combinations," *Journal of Experimental Psychology: Learning, Memory, and Cognition* 24 (4), 904–921. doi:10.1037/0278-7393.24.4.904.

Saltzman, E. L. and Munhall, K. G. (1989), "A Dynamical Approach to Gestural Patterning in Speech Production," *Ecological Psychology* 1 (4), 333–382. doi:10.1207/s15326969eco0104_2.

Seyfarth, S., Garellek, M., Gillingham, G., Ackerman, F., and Malouf, R. (2018), "Acoustic Differences in Morphologically-Distinct Homophones," *Language, Cognition and Neuroscience* 33 (1), 32–49. doi:10.1080/23273798.2017.1359634.

Stemberger, J. P. (1985), An Interactive Activation Model of Language Production, in A. Ellis, ed., *Progress in the Psychology of Language*, London: Lawrence Erlbaum Associates, pp. 143–186.

Stemberger, J. P. (2017), "Morphology in Language Production with Special Reference to Connectionism," in *The Handbook of Morphology*, Hoboken, NJ: John Wiley & Sons, Ltd., pp. 428–452.

Story, B. H. (2005), "A Parametric Model of the Vocal Tract Area Function for Vowel and Consonant Simulation," *The Journal of the Acoustical Society of America* 117 (5), 3231–3254. doi:10.1121/1.1869752.

Tomaschek, F., Arnold, D., Sering, K., Tucker, B. V., van Rij, J., and Ramscar, M. (2020), "Articulatory Variability Is Reduced by Repetition and Predictability," *Language and Speech* 64 (3), 654–680. doi:10.1177/0023830920948552.

Tomaschek, F., Plag, I., Ernestus, M., and Baayen, R. H. (2019), "Phonetic Effects of Morphology and Context: Modeling the Duration of Word-Final S in English with Naïve Discriminative Learning," *Journal of Linguistics* 57 (1), 123–161. doi:10.1017/S0022226719000203.

Tomaschek, F., Tucker, B. V., Fasiolo, M., and Baayen, R. H. (2018), "Practice Makes Perfect: The Consequences of Lexical Proficiency for Articulation," *Linguistics Vanguard* 4 (2). doi:10.1515/lingvan-2017-0018.

Tomaschek, F., Tucker, B. V., Ramscar, M., and Harald Baayen, R. (2021), "Paradigmatic Enhancement of Stem Vowels in Regular English Inflected Verb Forms," *Morphology* 31 (2), 171–199. doi:10.1007/s11525-021-09374-w.

Tucker, B. V. (2019), "Psycholinguistic Approaches to Morphology: Production," in *Oxford Research Encyclopedia of Linguistics*. doi:10.1093/acrefore/9780199384655.013.597.

Tucker, B. V., Sims, M., and Baayen, R. H. (2019), Opposing Forces on Acoustic Duration. Technical report. *PsyArXiv*. doi:10.31234/osf.io/jc97w.

Turk, A. and Shattuck-Hufnagel, S. (2020), *Speech Timing: Implications for Theories of Phonology, Phonetics, and Speech Motor Control*. Oxford: Oxford University Press.

Walker, G. M. and Hickok, G. (2016), "Bridging Computational Approaches to Speech Production: The Semantic–Lexical–Auditory–Motor Model (SLAM)," *Psychonomic Bulletin & Review* 23 (2), 339–352. doi:10.3758/s13423-015-0903-7.

Zwitserlood, P. (2018), "Processing and Representation of Morphological Complexity in Native Language Comprehension and Production," in G. Booij, ed., *The Construction of Words: Advances in Construction Morphology*, Cham: Springer International Publishing, pp. 583–602.

Zwitserlood, P., Bölte, J., and Dohmes, P. (2002), "Where and How Morphologically Complex Words Interplay with Naming Pictures," *Brain and Language* 81 (1), 358–367. doi:10.1006/brln.2001.2530.

7

IMPACT OF MORPHOLOGY ON WRITTEN WORD PRODUCTION

An Overview of Empirical Evidence and Theoretical Implications

Christina Gagné, Thomas L. Spalding and Alexander Taikh

Introduction

Typing and handwriting have been used to evaluate a range of issues relevant to cognitive processing, most notably attention, cognitive control, and skill acquisition (see Yamaguchi, 2019 for an overview of 100 years of typing research and Lambert & Quémart, 2019 for an overview of handwriting research). Research on typing has fallen into two main divisions: studies aiming to understand motor planning and automaticity, and studies aiming to understand cognitive processing and language production. Research on handwriting has had a similar focus, in that it has examined motor planning and execution as well as the cognitive processes underlying written production. More recently, and central to this chapter, research on these forms of written language production has been used to provide insight into the structure of multimorphemic words. In this chapter, we begin by outlining theoretical approaches that have been proposed for written production, before discussing key empirical findings concerning the processing of multimorphemic words. We end the chapter with a brief discussion of the theoretical implications of key findings for opposing theoretical frameworks.

Theoretical Approaches

There are a variety of approaches to the study of the nature of the production system. We will first discuss theoretical approaches to typing and then follow with approaches to handwriting. A key difference among the theories is whether linguistic information is available and used during the motor output process (i.e., while the keypresses are being executed) or whether this information only plays a role in the initial stages (e.g., during word identification and motor planning).

DOI: 10.4324/9781003159759-7

Some theories suggest that the influence of linguistic information on typing is limited to the initial planning of the motor output. For example, the Context Retrieval and Updating (CRU) model (Logan, 2018; Logan & Crump, 2011) uses a two-process model in which information is passed from the word level to the lower letter level. The letter level decomposes the word into individual letters, translates the letters to keystrokes, and implements the keystroke. The processes that represent and select a lexical item (i.e., a word) are separate from the processes that produce the keystrokes associated with the letters of that word. Because orthographic word forms are retrieved prior to initiating motor planning and output, the motor output (i.e., the execution of the keystrokes) is impervious to the influence of lexical, morphological, and semantic information. Similar to the CRU model, the approach developed by Yamaguchi et al. (2017) also uses a two-process model in which information is passed from the word level to the lower letter level. Yamaguchi et al. (2017) propose that memory chunks formed during typing experiences are part of the outer (word level) process. Chunks consist of associations among co-occurring letters, which then operate as a single representation but do not correspond to morphemes or other meaningful linguistic units. We should note that neither model mentions or uses morphological information.

Other models that focus primarily on motor planning and execution also posit separate levels for cognitive processing and motor processing but do allow for lexical information to exert an influence on the typing, because this information remains available after motor processing has been initiated. For example, Scaltritti et al. (2016) propose a cascaded model in which information flows between the lexical access level and the response execution level and, consequently, allows lexical-semantic variables, such as lexicality (i.e., whether an item is a word or non-word) and word frequency to influence response execution. In their model, lexical-orthographic information remains available after the motor programs are initiated, and influences the control system processes that operate after a motor program has been selected. Will et al. (2006) also suggest that the input to the motor system uses sub-word units rather than fully specified words. Similar to Scaltritti et al. (2016), they propose a cascaded model in which different processing levels (i.e., lexical, post-lexical, and motor) work in parallel, which allows typing to be influenced by linguistic information during motor execution because words are processed in sequences of sub-word units (such as syllables and morphemic units).

Weingarten (2005; Weingarten et al., 2004) also proposes a model in which linguistic information, including morphological information, can influence motor execution. In this model, typing begins with a frame for the whole word as well as sub-word frames based on the syllabic and morphological structure of the word. This theory posits that segmental information (i.e., information about the pieces or segments of a word, such as the *snow* and *-ing* in the word *snowing*) is not fully available at the beginning of a word or syllable but instead is accessed during motor execution through the use of a Graphemic Output Buffer that temporarily stores abstract orthographic representations of letters prior to their production. Similarly, Nottbusch et al. (2007) argue for the use of smaller linguistic units during typing, and propose that, prior to the production of a word, graphemic and word structure information is generated but segmental information is not fully specified. During output, the system goes through a hierarchy of processing steps during which segmental information is retrieved. Other frameworks (e.g., Gentner et al., 1988; Pinet et al., 2016) have similar processing assumptions in which written word production involves multiple levels of representation (e.g., word level, syllable level, and letter level). For example, Pinet et al. (2016) propose a hierarchical model in which syllables act as a level of processing between word access and letter output.

Although several theories have proposed models that have specialized linguistic modules (such as a semantic and syntactic system), spelling modules (that include information about orthographic representations, syllables, letters, and bigrams), and motor modules, the models do not always directly incorporate or allow for the use of morphological information. Instead, syllabic structure has received more attention. Nonetheless, there are some approaches that do explicitly make use of morphological units (Gagné & Spalding, 2014b, 2016a; Libben & Weber, 2014; Libben et al., 2012; Weingarten, 2005). For example, Libben (2020) posits that the system prepares motor plans for each constituent in a compound. Gagné and Spalding (2014b, 2016a, 2016b) also suggest that typing is sensitive to morphological structure. During typing, morphemes act as planning units, in that the motor plan includes information about the morphemes and their place within the word's morphemic structure, and consequently, the initiation of a morpheme (e.g., the start of *house* when typing *schoolhouse*) involves re-accessing the associated morpheme as well as maintaining a representation of the entire word.

As with typing, much early work on handwriting focused on the motor processes driving the output (for a review, see Van Galen, 1991). Van Galen (1991), however, presented an integrated theory of handwriting with a set of assumptions about the kinds of modules that are required, how those modules are ordered in their processing, and how they overlap in time. Modules for message generation (message intention, semantics, and syntax) were borrowed from speech production models. Once an intended message is identified, then a module for spelling the to-be-produced word is active, followed by a module for allograph selection. Allographs are different forms (e.g., upper or lower case, typed or handwritten, different fonts) of a letter. Following this, modules for size control and muscular adjustment provide the more fine-grained control to carry out the physical movements to actually produce the handwriting. The model assumes mixed parallel (or cascaded) and serial processing, such that the processes within a module are largely serial, but, due to the relatively slow speed of handwriting output, the modules themselves operate in an at least a partially parallel manner, with higher-level modules operating further ahead in the message than lower-level modules such that lexical and semantic information can remain available after the motor process is initiated. This assumption is critical, as it provides the mechanism by which processing in earlier modules can compete for resources with the output modules, and hence how, for example, factors affecting the spelling module can affect the speed of production of individual letters. In sum, processing in preparation for a given letter overlaps in time with the output of the previous letter, and processing of, say, spelling for a particular word overlaps in time with the output of (part of) the previous word. In addition, because of the difference in time alignment across various kinds of processing, there is an assumption that some outputs from a "higher" module have to be stored for some time to be available to the "lower" module at the right time point. This storage can be a locus for competition, as well. For example, if a number of letters are stored in a buffer, then one might see a speed up in letter production over the course of a word, as fewer letters are in the buffer, making the selection of the correct letter for output easier and faster.

Recent work has focused to a large extent on the spelling and allograph (e.g., A vs. a) selection modules, fleshing out the processing modules required to generate the correct spelling of a word and to select letters for output (e.g., Kandel et al., 2011). The key insight in much recent work is that spelling and letter selection for output are the result of hierarchically structured processing with levels between the word and the individual letter, including syllables and complex graphemes. Kandel et al. (2012) demonstrate the need to include morphology in this area of the model, but make the point that some form of coordination (as yet not known) needs to operate to deal with the fact that the processing is structured by both morphology and syllables, but that these two are not hierarchically structured—syllable and morpheme boundaries do not always line up, and morphemes are sometimes multisyllabic and sometimes just a single syllable and sometimes just a part of a syllable. Additionally, the relative importance of syllables and morphemes may depend on the language under consideration, as, for example, French is heavily syllabic (see, e.g., Kandel et al., 2006) whereas Arabic handwriting appears to be structured more by morphemes (e.g., Khoury-Metanis et al., 2018).

Key Findings in Written Production Research

Although typing performance is influenced by physical factors such as the keyboard layout and the physical constraints of the hands (Cooper, 1983; Gentner et al., 1988; Ostry, 1983), some research indicates that typing speed is influenced by the linguistic properties of a word. However, there remains much debate about which properties affect typing and also whether they exert an influence in all situations.

A consistent finding in typing is that interkey time shows an inverted U-shaped pattern across the word, in that, after the initial keypress, typing time on each letter increases, only to decrease around mid-word. This pattern had originally been attributed to the influence of word length (e.g., Ostry, 1983), but the syllable and morpheme structure of the words were neither mentioned nor analyzed as a potential cause of this pattern. However, there has been some research directly examining the role of a word's structure that has found that typing latencies are affected by syllable boundaries (Gentner, 1983; Pinet et al., 2016; Scaltritti et al., 2016; Weingarten, 2005; Weingarten et al., 2004), in that there is generally an increase in typing latencies when transitioning from one syllable to the next: the typing latency for first letter of the next syllable is longer than the latency for the last letter of the preceding syllable.

What about morphological structure? Not all studies examining syllable effects considered the morphological structure of the words. For example, Scaltritti et al. (2016) had participants type the names of 260 pictures, and found that typing latency for the first letter after the syllable boundary was longer than the latency for the preceding letter. Although the researchers did not mention or analyze the morphemic structure of the labels for the pictures, the English names for the pictures consisted of a mixture of word types: some (the majority) were monomorphemic (e.g., *bow, bird*, and *beetle*), some were suffixed (e.g., *glasses*), and some were compounds (e.g., *butterfly*), and it is likely that the Italian picture names also contained a mixture of morphological structures, especially given that Italian has a very rich inflectional morphology. Thus, it is not clear whether the increase in typing latencies at the syllable boundary was also partly due to transitioning across a morpheme boundary.

However, several studies have specifically considered the role of morphemic structure. For example, Weingarten (2005) notes that accelerations and decelerations in typing latencies are highly correlated with syllabic word structure and with morphological structure, in that typing latencies at the start of a syllable or morpheme are higher than for other letters within the subunit. Consistent with this observation, several studies have found that typing latencies for the initial letter of the second constituent are longer relative to the latency for the final letter of the first constituent (e.g., when typing *rosebud*, the typing latency for the letter *b* is longer than the latency for *e*). This morpheme boundary effect has been observed in English (Gagné & Spalding, 2014a, 2014b, 2016a, 2016b; Libben & Weber, 2014; Libben et al., 2012) and in German (Nottbusch et al., 2007; Sahel et al., 2008; Will et al., 2006).

Although morpheme boundaries tend to coincide with syllable boundaries, there has been some evidence that the elevation at the morpheme boundary is not entirely due to syllable structure. For example, typing latencies at the boundary are longest when the syllable and morpheme boundary coincide compared to when the letters correspond to either a pure syllable or pure morpheme boundary (Weingarten et al., 2004; Will et al., 2006). Further evidence that typing is sensitive to morphemic structure comes from Libben (2020), who examined novel compounds that varied in terms of whether they had one parse (e.g., *anklecob* -> [ankle] + [cob]) or two parses (e.g., *clampeel* -> [clam] + [peel] or [clamp] + [eel]). Ambiguous compounds (e.g., *clampeel*) showed moderately elevated typing times at the two boundary regions, whereas unambiguous compounds (e.g., *anklecob*) showed a spike, which suggests that the system has access to potential subunits of a word and attempts to maintain multiple possible representations during production. Other evidence that morphological structure is used was observed in research involving pseudo-compound words (Gagné & Spalding, 2016a). Pseudo-compounds are words that do not have a compound structure but contain two free morphemes and thus appear to have a compound structure; for example, the morphemic structure of *carrot* is not [[car] + [rot]]. Gagné and Spalding (2016a) found a slowdown in typing latency for pseudo-compounds as in compound words, except the slowdown occurred one letter before the end of the first pseudo-constituent for pseudo-compounds (e.g., at the *a* during the typing of *carrot*).

Morphological structure affects processing not only at the morpheme boundary but at other positions. For example, Gagné and Spalding (2016a) examined the processing dynamics across the production of the entire word in addition to evaluating processing at the morpheme boundary by comparing the processing of compounds, pseudo-compounds, and control words that were matched in length and frequency and number of syllables. Typing latencies decreased across the word for all three word types, but the rate of speed-up across the word was faster for compounds than for matched control words. In contrast, the rate of speed-up did not differ for pseudo-compounds and the matched control words, which indicates that it was not the presence of morphemes per se that sped up the processing of the compound words across the word, but rather it was morphemes' truly being a part of a compound structure that sped it up (which was not the case for pseudo-compounds). Feldman et al. (2019) also found changes in typing production across the course of typing affixed and pseudo-affixed words, which further suggests that morphemic structure affects output at letters other than just those involved in the morpheme boundary.

The influence of morphological structure is not straightforward, in that it is affected by other linguistic factors. One linguistic factor that influences how morphological structure affects typing is word frequency. The findings are mixed in terms of when word frequency exerts an influence. In some studies, typing latencies at the morpheme or syllable boundary were faster for high-frequency words than for low-frequency words for stimuli where the morpheme and syllable boundary coincided (e.g., *Roll-schuh* "roller-skate"). Weingarten et al. (2004) examined the typing of German words and manipulated the morpheme structure of the words by using stem-stem, stem-suffix, and prefix-stem words. Typing of the two letters straddling the boundary was faster for high-frequency than low-frequency words only for the stem-stem words (i.e., for compound words). In contrast, Gentner et al. (1988) found that latencies at the central interval of the word were faster for high-frequency words than for low-frequency words for items that were not compounds (e.g., the *st* in *oyster*). In a subsequent analysis, they examined whether this influence occurred even when controlling the syllable boundary by separating the words into two sets depending on whether the central interval spanned a syllable boundary or not, and found that typing at the central interval was faster for high-frequency words than for low-frequency words regardless of whether the interval coincided with a syllable boundary. However, Gentner et al. (1988)'s study did not examine or report the morpheme structure of the items, so it is unclear whether the elevation in average latencies in the central region of a word corresponded to morpheme boundaries.

The type of morpheme and position of the morpheme also influence the size of the effect of word frequency during typing. Feldman et al. (2019) found that higher-frequency English affixed and pseudo-affixed words were typed more quickly than were lower-frequency words and that the influence of word frequency was more pronounced during the production of the affix than of the stem. Sahel et al. (2008), as did Weingarten et al. (2004), examined the typing of German words and found that the frequency of the whole word and the frequency of the second constituent predicted the typing latencies at the morpheme boundary.

A second linguistic factor that impacts the influence of morphological structure on typing is type of morpheme. For example, Weingarten et al. (2004) noted that in German stem morphemes and syllables always coincide but that this is not the case for inflectional and derivational morphemes. Also, Feldman et al. (2019) examined typing latencies within the stem of affixed (e.g., *renormalize*) and pseudo-affixed words (e.g., *renormalist*) and found that typing performance was affected by lexicality (the consistency of the upcoming affix with the stem), in that average latencies were longer for prefix-stem words than for suffix words whereas latencies were shorter for prefix-nonwords than for suffix words. In addition, the typing of the affix was more influenced by word frequency than was the typing of the stem, which, in addition to the influence of lexicality, indicates that typing is sensitive to knowledge about morpheme types.

A third linguistic factor that impacts the influence of morphological structure on typing is semantic transparency (e.g., Gagné & Spalding, 2016a, 2016b; Libben & Weber, 2014). Semantic transparency refers to the extent to which the meaning of the whole word can be derived from the meaning of the constituents. Libben and Weber (2014) found that the size of the boundary effect was affected by semantic transparency of constituents such that the increase in typing latency at the morpheme boundary was largest for transparent-transparent (TT) compounds (e.g., *rosebud*) and smallest for opaque-opaque (OO) compounds (e.g., *hallmark*). The increase in latency for partially opaque compounds (opaque-transparent, OT, e.g., *jackknife*, and transparent-opaque, TO, e.g., *cardshark*) were in between.

Gagné and Spalding (2014b) also found that the boundary effect was larger for TT compounds than for OT compounds. In addition, they observed that this increase was due to the semantic transparency of the first constituent, in that typing time for the last letter of the first constituent was faster for compounds with transparent first constituents than for compounds with opaque first constituents. Typing time for the first letter of the second constituent did not differ for TT and OT compounds. Consistent with these results, Gagné and Spalding (2016a) used two measures of semantic transparency (dichotomous classification and continuous ratings) and found that, regardless of which measure was used, typing latencies at the morpheme boundary were larger when the first constituent was transparent than when it was opaque. These results indicate that sensitivity to semantic transparency differs depending on the morphological position.

Further evidence that morphological and semantic information mutually affect typing production comes from the finding that the influence of semantic transparency on typing latencies at the morphemic boundary is sensitive to recent exposure to a word that is semantically related to the first constituent. For example, in Gagné and Spalding (2014b) participants were briefly presented with a word (a prime) prior to seeing and typing a compound word. The prime was either semantically related (e.g., *hay*) or unrelated to the first constituent of the compound (e.g., *strawberry*). The impact of the semantically related prime depended on the semantic transparency of the head of the compound. When the prime was unrelated to the first constituent, the elevation in typing at the morpheme boundary for TT compounds was larger than for OT compounds. However, when the prime was semantically related to the first constituents, the elevation at the boundary did not differ for TT and OT compounds. In contrast, the boundary effect was larger for OO compounds than for TO compounds regardless of whether the prime was semantically related. Subsequent research (Gagné & Spalding, 2016b) also found that the semantic transparency of the head (the second constituent in English) affected the influence of a semantic prime such that, for compounds with transparent heads, typing the first letter of the second constituent was slower when the prime was semantically related than when the prime was unrelated. In contrast, for compounds with opaque heads, typing the first letter of the second constituent was faster when the prime was semantically related than when the prime was unrelated.

In summary, there have been several findings that point to the involvement of morphological information during typing. Elevations in latency occur at the morpheme boundary, and the size and nature of these elevations are influenced by other linguistic factors such as word frequency, constituent frequency, morpheme type, semantic transparency, and number of morphological parses.

As with research on typing, much research on handwriting has focused on the issues of how central (language) processes interact with "peripheral" (in the case of handwriting, graphomotor) processes. The relatively recent wider availability of digitizing tablets has made research on handwriting more practical, and hence has widened the field considerably. The methodology of handwriting research is quite similar to that found in typing research, with one fairly major exception. As with typing research, handwriting research can focus on errors (e.g., Berg, 1996, 2002) or on the online characteristics of production. In terms of online production, one can look at either initiation time (i.e., time to start writing the word) or on the inter-letter interval. However, another measure that is relatively unique to handwriting is the time to produce an individual letter (i.e., the time from the beginning of the production of a given letter to the end of production of that individual letter). Obviously, this last measure does not have a clear analog in the typing literature, because in typing research one generally measures the time from keystroke to keystroke, so this includes both the inter-letter time, per se, and the movement time for the keystroke of the second letter. In some handwriting research, participants lift the stylus at the end of a letter and then lower it to begin the second letter, so that both the time between the letters and the duration of the letter production can be captured. In other handwriting research (as with connected cursive handwriting), the division between letters is identified by velocity and direction of movement of the recorded strokes, hence the velocity of the connecting strokes can be compared across various manipulations. The value of this ability to separate production of individual letters is this: because handwritten letter production is extended in time, the production duration (or movement velocities) of the individual letter can be sensitive to both graphomotor processes and, potentially, central (language) processes. The separation of these two measures in handwriting offers researchers the potential to differentiate effects loading on the individual letter plan from those loading on the individual letter output process.

Relatively little work has, so far, focused specifically on morphology, however. Instead, much work on handwriting has focused on developmental and educational concerns (e.g., Suárez-Coalla et al., 2017). This is perhaps unsurprising, due to the role of handwriting in early education and the central educational concern surrounding children learning to spell, though this may be on the point of changing as many schools have begun to de-emphasize handwriting and some have begun instead to emphasize typing, due to the widespread change in the relative importance of handwriting and typing in life outside of school (see, e.g., the discussions in Lambert and Quémart, 2019 and Longcamp et al., 2005). Perhaps partly due to handwriting's role in education, some work on handwriting has focused on central (language) processing issues relating specifically to the development of language skills (e.g., Longcamp et al., 2005) and the role of graphomotor skill level in facilitating the development of language and/or cognitive skills (e.g., Mangen et al., 2015), whereas such research in typing has been relatively rare until recently (see, e.g., Pinet et al., 2016). Lambert and Quémart (2019) provide a recent overview of handwriting research.

In addition to the more educationally oriented research, much research has investigated the role of orthographic characteristics such as bigrams, repeated letters, complex graphemes, and spelling regularity (Bonin et al., 2001; Hess et al., 2020; Kandel et al., 2011; Kandel & Spinelli, 2010; Lambert & Quémart, 2019; Orliaguet & Boë, 1993; Shen et al., 2013). In addition, the role of syllables has been of interest in handwriting, as it recently has in typing (e.g., Kandel et al., 2006; Kandel et al., 2011; Kandel & Soler, 2009; Van Galen, 1991). As with typing research, there are clear, but complicated, effects of these various aspects of word structure on handwriting production.

Recently, however, morphological effects have been investigated (Kandel et al., 2008; Kandel et al., 2012; Quémart & Lambert, 2019; Suárez-Coalla et al., 2017). The results here seem to be largely parallel to those found in typing, namely, that morphology plays a role in the output of handwritten language. In particular, morphological boundaries lead to increased inter-letter intervals and increased letter-writing times for the letter previous to the boundary, both of which are taken to reflect competition for resources between the central modules (e.g., morphological processing within the spelling module) and the peripheral modules responsible for the ongoing output. On the other hand, not all morphemes are created equal in this situation, with suffixes showing the described effects but not the prefixes (e.g., Kandel et al., 2012).

Implications and Conclusions

The implications of the research on written word production are twofold with respect to morphology. First, we see that morphology does indeed influence written production, whether typing or handwriting, and that it does so in conjunction with other factors, lexical, orthographic, syllabic, and so on. Thus, the results argue against a strictly modular system in which motor execution is independent of linguistic influence, and are more compatible with a system in which linguistic information is able to affect motor execution. However, many questions remain. Second, we see that both typing and handwriting, due to their extended time of production and linear ordered output, are excellent methods for studying the effects of morphology. It allows researchers to study the varying influence that morphology has at different regions of the text as processing unfolds in time.

References

Berg, T. (1996). The modality-specificity of linguistic representations: evidence from slips of the tongue and the pen. *Journal of Pragmatics*, 27(5), 671–697. doi:10.1016/s0378-2166(96)00059–00058.

Berg, T. (2002). Slips of the typewriter key. *Applied Psycholinguistics*, 23, 185–207. doi:10.1017/S0142716402002023.

Bonin, P., Peereman, R., & Fayol, M. (2001). Do phonological codes constrain the selection of orthographic codes in written picture naming? *Journal of Memory and Language*, 45(4), 688–720. doi:10.1006/jmla.2000.2786.

Cooper, W. E. (1983). *Cognitive Aspects of Skilled Typewriting*. New York: Springer.

Feldman, L. B., Dale, R., & van Rij, J. (2019). Lexical and frequency effects on keystroke timing: challenges to a lexical search account from a type-to-copy task. *Frontiers in Communication*, 4. doi:10.3389/fcomm.2019.00017.

Gagné, C. L., & Spalding, T. L. (2014a). Adaptation effects in lexical processing. *Suvremena Lingvistika (Contemporary Linguistics)*, 40(78), 127–149. https://hrcak.srce.hr/clanak/194020.

Gagné, C. L., & Spalding, T. L. (2014b). Typing time as an index of morphological and semantic effects during English compound processing. *Lingue e Linguaggio*, XIII(2), 241–262. doi:10.1418/78409.

Gagné, C. L., & Spalding, T. L. (2016a). Effects of morphology and semantic transparency on typing latencies in English compound and pseudocompound words. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, 42(9), 1489–1495. doi:10.1037/xlm0000258.

Gagné, C. L., & Spalding, T. L. (2016b). Written production of English compounds: Effects of morphology and semantic transparency. *Morphology*, 26(2), 133–155. doi:10.1007/s11525-015-9265-0.

Gentner, D. R. (1983). Keystroke timing in transcription typing. In *Determinants of Interkey Times in Typing* (pp. 95–120). New York: Springer.

Gentner, D. R., Larochelle, S., & Grudin, J. (1988). Lexical, sublexical and peripheral effects in skilled typewriting. *Cognitive Psychology*, 20(4), 524–548. doi:10.1016/0010-0285(88)90015-1.

Hess, S., Mousikou, P., & Schroeder, S. (2020). Double-letter processing in developmental and skilled handwriting production: evidence from kinematics. *Quarterly Journal of Experimental Psychology*, 73(9), 1396–1406. doi:10.1177/1747021820908538.

Kandel, S., Alvarez, C. J., & Vallée, N. (2006). Syllables as processing units in handwriting production. *Journal of Experimental Psychology: Human Perception and Performance*, 32(1), 18–31. doi:10.1037/0096-1523.32.1.18.

Kandel, S., Álvarez, C. J., & Vallée, N. (2008). Morphemes also serve as processing units in handwriting production. In M. Baciu (Ed.), *Neuropsychology and Cognition of Language:*

Behavioural, Neuropsychological and Neuroimaging Studies of Spoken and Written Language (pp. 87–100). Research Signpost. https://hal.inria.fr/hal-00401659/.

Kandel, S., Peereman, R., Grosjacques, G., & Fayol, M. (2011). For a psycholinguistic model of handwriting production: testing the syllable-bigram controversy. *Journal of Experimental Psychology: Human Perception and Performance*, 37(4), 1310–1322. doi:10.1037/a0023094.

Kandel, S., & Soler, O. (2009). Differential syllable effects when learning to write French and Catalan words. *Current Psychology Letters: Behaviour, Brain, & Cognition*, 25(3), 1–11. doi:10.4000/cpl.4965.

Kandel, S., & Spinelli, E. (2010). Processing complex graphemes in handwriting production. *Memory & Cognition*, 38(6), 762–770. doi:10.3758/mc.38.6.762.

Kandel, S., Spinelli, E., Tremblay, A., Guerassimovitch, H., & Álvarez, C. J. (2012). Processing prefixes and suffixes in handwriting production. *Acta Psychologica*, 140(3), 187–195. doi:10.1016/j.actpsy.2012.04.005.

Khoury-Metanis, A., Asadi, I. A., & Khateb, A. (2018). The contribution of basic linguistic skills to handwriting among fifth-grade Arabic-speaking children. *Writing Systems Research*, 10(2), 95–110. doi:10.1080/17586801.2018.1540375.

Lambert, E., & Quémart, P. (2019). Introduction to the special issue on the dynamics of written word production: methods, models and processing units. *Reading and Writing*, 32 (1), 1–12. doi:10.1007/s11145-018-9929-3.

Libben, G. (2020). What can we learn from novel compounds? In S. Schulte im Walde & E. Smolka (Eds.), *The Role of Constituents in Multiword Expressions: An Interdisciplinary, Cross-Lingual Perspective* (pp. 107–127). Berlin: Language Science Press.

Libben, G., & Weber, S. (2014). Semantic transparency, compounding, and the nature of independent variables. In F. Rainer, W. Dressler, F. Gardani, & H. C. Luschutzky (Eds.), *Morphology and Meaning* (pp. 205–222). Amsterdam: John Benjamins.

Libben, G., Weber, S., & Miwa, K. (2012). P3: a technique for the study of perception, production, and participant properties. *The Mental Lexicon*, 7(2), 237–248. doi:10.1075/ml.7.2.05lib.

Logan, G. D. (2018). Automatic control: how experts act without thinking. *Psychological Review*, 125(4), 453–485. doi:10.1037/rev0000100.

Logan, G. D., & Crump, M. J. C. (2011). Hierarchical control of cognitive processes: the case for skilled typewriting. In B. H. Ross (Ed.), *The Psychology of Learning and Motivation* (pp. 1–27). London: Academic Press.

Longcamp, M., Zerbato-Poudou, M.-T., & Velay, J.-L. (2005). The influence of writing practice on letter recognition in preschool children: a comparison between handwriting and typing. *Acta Psychologica*, 119(1), 67–79. doi:10.1016/j.actpsy.2004.10.019.

Mangen, A., Anda, L. G., Oxborough, G. H., & Brønnick, K. (2015). Handwriting versus keyboard writing: effect on word recall. *Journal of Writing Research*, 7(2), 227–247. doi:10.17239/jowr-2015.07.02.1.

Nottbusch, G., Weingarten, R. D., & Sahel, S. (2007). From written word to written sentence production. In G. Rijlaarsdam, M. Torrance, L. Van Waes, & D. Galbraith (Eds.), *Writing and Cognition: Research and Applications* (pp. 31–53). London: Elsevier.

Orliaguet, J.-P., & Boë, L.-J. (1993). The role of linguistics in the speed of handwriting movements: effects of spelling uncertainty. *Acta Psychologica*, 82(1), 103–113. doi:10.1016/0001-6918(93)90007-E.

Ostry, D. J. (1983). Determinants of interkey times in typing. In W. E. Cooper (Ed.), *Determinants of Interkey Times in Typing* (pp. 224–246). New York: Springer.

Pinet, S., Ziegler, J. C., & Alario, F. X. (2016). Typing is writing: linguistic properties modulate typing execution. *Psychonomic Bulletin Review*, 23(6), 1898–1906. doi:10.3758/s13423-016-1044-3.

Quémart, P., & Lambert, E. (2019). The influence of the morphological structure of words on the dynamics of handwriting in adults and fourth and sixth grade children. *Reading and Writing*, 32(1), 175–195. https://doi.org/10.1007/s11145-017-9762-0.

Sahel, S., Nottbusch, G., Grimm, A., & Weingarten, R. (2008). Written production of German compounds: effects of lexical frequency and semantic transparency. *Written Language & Literacy*, 11(2), 211–227. doi:10.1075/wll.11.2.06sah.

Scaltritti, M., Arfe, B., Torrance, M., & Peressotti, F. (2016). Typing pictures: linguistic processing cascades into finger movements. *Cognition*, 156, 16–29. doi:10.1016/j.cognition.2016.07.006.

Shen, X. R., Damian, M. F., & Stadthagen-Gonzalez, H. (2013). Abstract graphemic representations support preparation of handwritten responses. *Journal of Memory and Language*, 68(2), 69–84. doi:10.1016/j.jml.2012.10.003.

Suárez-Coalla, P., Martínez-García, C., & Cuetos, F. (2017). Morpheme-based reading and writing in Spanish children with dyslexia. *Frontiers in Psychology*, 8. doi:10.3389/fpsyg.2017.01952.

Van Galen, G. P. (1991). Handwriting: issues for a psychomotor theory. *Human Movement Science*, 10(2–3), 165–191. doi:10.1016/0167-9457(91)90003-g.

Weingarten, R. (2005). Subsyllabic units in written word production. *Written Language & Literacy*, 8(1), 43–61. doi:10.1075/wll.8.1.03wei.

Weingarten, R., Nottbusch, G., & Will, U. (2004). Morphemes, syllables, and graphemes in written word production. *Trends in Linguistics Studies and Monographs*, 157, 529–572. doi:10.1515/9783110894028.529.

Will, U., Nottbusch, G., & Weingarten, R. (2006). Linguistic units in word typing: effects of word presentation modes and typing delay. *Written Language & Literacy*, 9(1), 153–176. doi:10.1075/wll.9.1.10wil.

Yamaguchi, M. (2019). What 100 years of typing research can tell us. *Cognitive Bulletin*, 4, 25–33. doi:10.31234/osf.io/zr5nq.

Yamaguchi, M., Randle, J. M., Wilson, T. L., & Logan, G. D. (2017). Pushing typists back on the learning curve: memory chunking improves retrieval of prior typing episodes. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 43(9), 1432–1447. doi:10.1037/xlm0000385.

8

THE IMPACT OF SENTENCE CONTEXT ON THE MORPHOLOGICAL PROCESSING OF SINGLE WORDS

Electrophysiological Evidence

Sendy Caffarra

Word Recognition Processing and the Role of Sentence Context

Analyzing and combining words in sequences is a critical linguistic skill that underpins many forms of communication and interaction. Efficient sentence comprehension requires that our brains process single words and define how they are connected to other parts of a discourse or text. Detecting the dependencies between different sentential constituents largely relies on the analysis of sub-lexical items carrying morphological and morphosyntactic information (i.e., morphemes). In this sense, morphology is crucial for sentence analysis, as it conveys important information about the word's relationship to other sentential constituents. Sentence context and grammatical dependencies are relevant aspects of the study of morphology that have not received enough attention in past research. As a consequence, it is still unclear how our brain deals with this important source of linguistic information.

A number of theoretical models have highlighted the role of morphological regularity, suggesting it determines the type of cognitive processes applied during word recognition. Morphologically regular forms such as "walked" can be decomposed into two basic morphemes: the stem "walk," which carries the word's lexical information (e.g., its meaning, frequency, and grammatical category) and the affix "ed," which carries grammatical information (e.g., tense, person, and number). By contrast, irregular morphological forms such as "ran" cannot easily be decomposed into morphemic constituents; in such cases, a single linguistic entry jointly carries both lexical and grammatical information.

In line with this distinction based on compositionality and the two types of information available in a given word, some theoretical models assume two types of cognitive mechanisms: a mechanism that recovers lexical information from stems, and a mechanism that accesses grammatical features in affixes. Regular forms

DOI: 10.4324/9781003159759-8

would be decomposed and processed by these two distinct mechanisms operating independently, while irregular forms would require that both lexical and grammatical components be extracted simultaneously from a unique entry stored in memory. Theoretical models of word recognition differ in the weight they allocate to compositional or memory-based lexical processes (see Section 2).

Critically, all models largely agree that word recognition is carried out similarly regardless of whether a word appears in a word list or sentence. However, sentences represent a more ecological testing arena for word analysis, and understanding word recognition in sentential context might shed light on some aspects of linguistic computation that are not always relevant when a word is presented in isolation (e.g., syntactic and semantic word predictability, grammatical dependencies between different words, phrase–structure relations). These additional contextual factors might impact the way a word is morphologically analyzed and potentially decomposed. This chapter will focus on studies that have explored morphological analysis in sentences, and will highlight how sentential context might change the way we understand single words.

Morphological Models of Word Recognition

We can distinguish three different categories of theoretical models by the weights they attribute to compositional and lexical aspects of word recognition: (1) fully compositional models (also called "rule-based models"); (2) connectionist models (also called "lexicalist, associative, memory-based models"); and (3) dual-route models.

Compositional models assume common decompositional processing for both regular and irregular word forms (Chomsky & Halle, 1968; Halle & Marantz, 1993; Stockall & Marantz, 2006). In regular forms, lexical and grammatical information is retrieved separately after decomposing the word into its stem and affix; in irregular forms, a stem adjustment is required to perform a similar morphological decomposition. The benefit of such a rule-based mechanism is that it reduces potential cognitive load by applying the same cognitive operations to all linguistic entries, minimizing the differences between distinct lexical items.

Connectionist models, by contrast, do not assume any form of morphological decomposition and do not make a representational distinction between stems and affixes (Joanisse & Seidenberg, 1999; McClelland & Patterson, 2002; Rueckl et al., 1997; Rumelhart & McClelland, 1986). They propose that both regular and irregular forms are retrieved from memory thanks to the parallel activation of a range of linguistic features (e.g., phonological, orthographic, semantic), which are interactively represented in cognitive networks. The level of activation of each of these linguistic features largely depends on frequency. The advantage of such memory-based mechanisms is that they can easily be generalized to new lexical entries, regardless of their level of morphological regularity.

Dual-route models assume the coexistence of two distinct mechanisms (lexicalist and compositional) that are selectively applied for regular and irregular forms (Clahsen, 1999; Marslen-Wilson & Tyler, 1997, 1998; Pinker, 1991; Pinker & Ullman, 2002; Pinker & Prince, 1994; Sonnenstuhl et al., 1999; Ullman, 1999, 2001, 2004). Rule-based processing is carried out on regular forms, while irregular forms are analyzed through a memory-based mechanism. These models combine the advantages of the compositional and connectionist models described above, and provide a theoretical framework that is not specific to language but can be generalized to other cognitive domains (Pinker, 1999; Pinker & Ullman, 2002).

Two aspects of these theoretical categorizations are critical and will be further discussed in this chapter. First, the existence of dual mechanisms was originally proposed based on research on English, which exhibits strong differentiation between regular and irregular morphological forms. However, morphologically richer languages provide a gradient of morphological variability, offering an additional testing arena for the abovementioned models. Second, all these models assume that morphological analysis operates in the same way regardless of the context in which a word is presented (e.g., in a word list or sentence). Analyzing words embedded in sentences might increase the relevance of between-word dependencies and the importance of covariance between morphological features across different sentential constituents (Barber & Carreiras, 2005; Molinaro et al., 2012). When the cognitive system operates at the level of the sentence, the morphological analysis of a single word might interact with morphological information available from other parts of the sentence. Thus, studying morphological analysis in sentential contexts should provide a broader and more ecological picture of word analysis.

Electrophysiological Techniques Used to Study Morphological Analysis

Among all the techniques used to examine morphological processing within sentential contexts, electrophysiology has the great advantage of being able to temporally localize the neural correlates specific to a single word, even when that word is presented in a complex sequence of sentential constituents. To track the time course of single word being processed within a sentence context, most electrophysiological studies adopt a rapid serial visual presentation, where the sentence is presented word by word. Although this modality of presentation makes the sentence reading task less ecological, it enables us to unambiguously localize a temporal window where neural responses can be reliably related to the analysis of a specific word. More ecological paradigms (e.g., co-registration of EEG and eye-tracking; see Degno et al. 2019; Dimigen & Ehinger, 2019; Weiss et al., 2021) are becoming more common, but to our knowledge they have not been employed yet to study morphology within the context of sentence comprehension.

Electroencephalography (EEG) and rapid visual presentation have been widely used to study how the brain treats different types of linguistic information (including morphology) when presented within a sentence. The EEG signal represents changes across time in the electrophysiological activity recorded from different sites on the scalp of a participant. From the EEG signal, evoked-related potentials (ERPs) can be extracted and interpreted. ERPs (or their magnetic counterparts, ERFs) represent variations in electrophysiological responses to a specific temporal event, such as the onset of a spoken or written word presented in a text. These neural correlates show how the brain responds to an external event with extremely high temporal resolution (up to 1 ms). ERPs are represented as waveforms and are characterized by three main characteristics: polarity (positive- or negative-going), timing (the point in time where the amplitude of the waveform reaches its maximum), and topographical distribution (the spatial portion of the scalp where the waveform amplitude reaches its maximum).

ERP studies on sentences have typically adopted violation paradigms, where two main conditions are compared: a (semantically, morphologically, grammatically) correct condition and a condition that is similar but includes a violation of a specific linguistic feature (e.g., morphology). The logic behind this approach is that the ERP changes observed when comparing the two conditions should be related to how the brain processes the specific linguistic feature that has been violated (as well as to error analysis processes).

ERP studies on morphology have used a range of violations mainly involving two types of morphemes: inflections and derivations. Inflectional morphemes specify the grammatical functions of a word (e.g., *-s* in *apples* is an inflectional morpheme specifying the grammatical number of the noun), while derivational morphemes generate new words that usually have a different grammatical category from the original one (e.g., *-er* in *driver* is a derivation that transforms a verb into a noun). Violation paradigms compare a correct and an incorrect morphological condition (correct and incorrect application of morphemes; e.g., *brought* vs. *bringed*). Morpheme violations have been reported to elicit amplitude modulations in a number of ERP responses. Below, we list the most important ERP correlates of language processing also reported in the study of morphology (see Sections 4 and 5): the N400, the LAN, and the P600.

The N400 is a negative-going waveform that peaks around 400 ms with a centro-posterior distribution. It has been related to aspects of lexical-semantic analysis and was initially observed in response to outright semantic violations (e.g., "He spread the warm bread with socks" as compared to "He spread the warm bread with jam"). The N400 effect typically consists of a greater negative amplitude for the violated than the controlled condition (Kutas & Federmeier, 2011).

The LAN is a negative-going waveform that also peaks around 400 ms. In contrast to the N400, the LAN topographic distribution is left anterior and is typically observed in response to morphosyntactic violations (e.g., a gender agreement violation in Spanish: "La casa es roja" [The$_F$ house$_F$ is red] as compared to "El casa es roja" [The$_M$ house$_F$ is red]). The LAN effect is also characterized by a greater negative amplitude for the violated than the control condition (Friederici, 2002).

The P600 is a positive-going waveform that reaches its maximum 500 ms after stimulus onset. It has been observed in response to a wide range of syntactic and semantic violations (e.g., word order violations, grammatical agreement violations, but also prediction errors) and is thought to be related to late processes of reanalysis, usually carried out to repair errors and reach a broad comprehension of the sentence's meaning. The P600 effect consists of an increased positive amplitude for the violated compared to the correct condition (Osterhout & Mobley, 1995).

Below, we provide a short summary of ERP findings related to morphological manipulations that have been observed for isolated words (without the sentential context), before considering the case of sentence analysis.

ERP Evidence on the Morphological Analysis of Isolated Words

A number of ERP studies adopting a violation paradigm have examined two types of morphological violations: overregularizations and irregularizations. Overregularizations are created by adding a regular affix to a word that requires an irregular affix (e.g., *bring-bringed*). Irregularizations are created by adding an irregular affix to a regular word (e.g., *seep-sept*). ERP findings have consistently shown LAN effects in the case of overregularizations but not in the case of irregularizations. These findings suggest that applying a regular morpheme (e.g., *-ed*) triggers morphosyntactic processes of decomposition, which are indexed by a LAN response (Gross et al., 1998; Penke et al., 1997; Weyerts et al., 1997). These findings support a certain degree of compositionality, which has been further confirmed by studies using different experimental paradigms (e.g., priming).

Within the priming studies, when existing morphologically regular targets are preceded by morphologically related (e.g., *walked-walk*) as compared to unrelated primes, a reduction of the N400 effect has been observed in response to the target word. This N400 suppression effect has not been observed for irregular forms (e.g., *taught-teach*). It has been interpreted as reflecting facilitated lexical access to regular targets that have already been activated by decomposition processes initiated during the presentation of the prime (e.g., *walk-ed*). This effect has been replicated with both inflections and derivations (Barber et al. 2002; Dominguez et al. 2004; Lavric et al., 2007; Morris et al., 2007; Morris et al., 2008; Münte et al., 1999).

Overall, these findings seem to be in line with dual-route models, which suggest that compositional processes are applied to regular forms while memory-based processes are applied to irregular forms. This interpretation assumes that distinct ERP components reflect different cognitive processes (memory-based and compositional). However, it is worth noting that alternative theoretical accounts have interpreted different ERP signatures as the temporal stages at which the morphological structure is accessed. These models assume that the same cognitive mechanisms are in place for regular and irregular forms, while the time course of morphological analysis (and the relative ERP markers) changes and depends on word regularity (Rastle et al., 2015).

Neuroimaging studies have provided further support for dual-route models by showing a dissociation between brain areas activated during the comprehension of morphologically regular forms (i.e., the frontal basal ganglia) and brain areas involved in the analysis of morphologically irregular forms (i.e., the temporal lobe Hoen & Dominey 2000; Ullman 2001). These two distinct brain circuits have been proposed to form part of two different memory systems (procedural and declarative) that are involved in qualitatively distinct cognitive computations (Ullman 2001). While the temporal lobe seems to be more involved in analyzing forms that are stored in memory as whole units, the basal ganglia are specialized in combinatorial processes that can be productively applied to regular lexical items.

ERP Evidence on Morphological Analysis in Sentences

ERP studies that have explored morphological violations in sentence contexts have provided partially overlapping results with those mentioned above together with new insights and some dissimilarities (see Table 8.1 for a detailed summary of the ERP results found in sentences).

Like the ERP studies on isolated words, a number of ERP findings in sentence contexts have provided evidence in favor of decomposition (Allen et al. 2003; Newman et al., 2007). LAN effects were replicated in the case of overregularizations of inflections in sentence contexts (written modality: Bartke et al., 2005; Linares et al., 2006; Penke et al., 1997; Schremm et al., 2019; Weyerts et al., 1997; auditory modality: Lück et al., 2006). This again confirms that compositional parsing takes place even when regular morphemes are encountered in complex texts. On the other hand, N400 effects (or no LAN effects) have been more frequently reported in response to irregularizations and derivation violations presented in sentences. This suggests the recruitment of lexical semantic processes when no real morpheme is available and the word at interest can be assimilated to a pseudo-word (Allen et al., 2003; Newman et al., 1999; Rodríguez-Fornells et al., 2001; auditory modality: Lück et al., 2006, but see Bölte et al., 2009). The contrast between LAN effects for overregularizations and N400 effects for irregularizations suggests a qualitative distinction in the processing of morphologically regular and irregular forms. These ERP findings are compatible with the dual-route model, and suggest that the distinction between rule-based and memory-based processes can be generalized to sentence analysis. These findings are also in line with the idea that different ERP signatures reflect similar morphological processes that are put in place at different temporal stages, depending on word regularity (Rastle et al., 2015).

Apart from these similarities, research using sentence contexts has revealed some new aspects of morphological analysis. These are listed below.

First, when comparing ERP findings for single words and sentences, some authors have noted that LAN effects are more frequently reported in ecological contexts such as passive sentence reading. Sentence paradigms might represent the best case scenario to boost the automatic combinatorial processes of morphological structure building (often indexed by LAN effects; Allen et al. 2003; Bölte et al., 2009; Leminen et al., 2016; Morris & Holcomb, 2005). Being able to quickly detect and decompose morphemes within a sentence is crucial to understand that sentence efficiently. Hence, in sentence contexts, any available morphological information is highly relevant for detecting grammatical dependencies and combining multiple lexical items. In addition, auditory presentation might facilitate

TABLE 8.1. Summary of EEG studies on morphological analysis in sentence comprehension. V: visual; A: auditory; Inf: inflection; Der: derivation.

Paper	*Language*	*Violation Type*	*Modality*	*Target word*	*Critical comparisons*	*Results*
Allen et al., 2003	English	Inf	V	verb	Regular vs irregular verbs with inflection and frequency violations	N400 frequency effect and P600 tense violation effect, with an interaction only for irregular verbs.
Bartke et al., 2005	German	Inf	V	noun	Irregular vs subregular nouns with inflection violations that could be high or low predictable	Reduced N400 effect for sub-regular as compared to irregular forms (in both correct and incorrect forms).
Bolte et al. 2009	German	Der	V	adjective	Adjectives vs pseudo-adjectives (semantically plausible or not) with a derivation violation.	LAN violation effect for pseudo as compared to real adjectives.
de Vega et al., 2010	Spanish	Inf	V	verb	Real and nonce verbs with inflection violations.	P200 effect for inflection violations. N400 effect for the lexical status of the verb.
Havas et al., 2012	Spanish	Der	V	noun	Violations of productive and unproductive noun derivations.	N400 effect for the violation of unproductive derivations. P600 effect for both derivation types.
Leinonen, 2008	Finnish	Inf/Der	V	noun	Violation of inflectional and derivational morphemes.	AN+P600 effects for inflectional violations. N400+P600 effects for derivational violations.
Leminen et al., 2016	Finnish	Inf	V	noun	Inflection violations at the lexical or phrase level.	N400 effect for violations at the word level (right temporal neural source). LAN effect for violations at the phrase level (left frontal source). P600 effect for both violations.

Paper	*Language*	*Violation Type*	*Modality*	*Target word*	*Critical comparisons*	*Results*
Linares, 2006	Spanish	Inf	V	verb	Marked vs unmarked stems with inflection violations.	N400 effect for stem violations. LAN-P600 effect for inflection violations.
Luck et al., 2006	German	Inf	A	noun	Regular vs irregular nouns with inflection violations.	LAN-P600 for over-regularizations. N400 effects for irregularizations.
Morris & Holcomb, 2005	English	Inf	V	verb	Regular vs irregular verbs with inflection violations.	LAN effects for both types of verb violations but bigger for overregularizations. P600 for both violations.
Newman et al., 2007	English	Inf	V	verb	Regular vs irregular verbs with inflection violations.	LAN effect for regular verb violations. P600 effect for both regular and irregular verb violations.
Penke et al., 1997	German	Inf	V	verb	Regular, irregular, and nonce verbs with inflection violations.	LAN violation effect for over-regularizations. N400 effect for nonce as compared to regular and irregular forms.
Rodrigues-Fornells et al., 2001	Catalan	Inf	V	verb	Violation of inflections and stem formation.	LAN effect for over-regularizations of stem formation, but not for inflection violations. P600 effect for both types of violations.
Schremm et al., 2019	Swedish	Inf	V	verb	Regular vs irregular verbs with inflection violations.	LAN for overregularizations, but not for irregularizations. P600 for all types of violations.
Weyerts et al., 1997	German	Inf	V	noun	Regular, irregular nouns with inflection violations.	LAN violation effect for over-regularizations. N400 for irregularizations.

morphological decomposition, since the auditory modality requires more sequential processing than the written modality (Lück et al., 2006).

Second, P600 effects have been more frequently reported in sentence studies than studies on single words. These P600 effects do not seem to be specific to a limited set of violations in sentence contexts, but have been reported in response to a large range of morphological and morphosyntactic errors (both overregularizations and irregularizations, both inflection and derivation violations, and grammatical agreement violations; Allen et al., 2003; Molinaro et al. 2011; Newman et al., 2007; Penke et al., 1997; Rodríguez-Fornells et al., 2001; Schremm 2009; cf. Morris & Holcomb, 2005). These late positive effects have been taken to reflect high-level control mechanisms of repair and reanalysis, which are essential for correcting errors and achieving a full understanding of sentences and texts.

Third, ERP sentence studies have shown that presenting words in context can shed light on the time course of different levels of language analysis (e.g., morphological, syntactic, and semantic (Leminen et al., 2016; Morris & Holcomb, 2005). Adding morphological violations to other types of linguistic manipulations has the potential to complement the knowledge provided by single-word studies. A small set of ERP studies have specifically compared the time course of morphological analysis with the time course of other types of processing (e.g., morphosyntactic and lexico-semantic). These preliminary results suggest that morphological decomposition happens at an early stage of parsing and is relatively independent from other sources of linguistic information. At a later stage of processing, interactive effects have been observed, indicating that morphological information is likely integrated at later stages of analysis (De Vega et al., 2010; Leminen et al., 2016).

Fourth, a large group of ERP studies on sentences in morphologically rich languages seems to suggest that the distinction between morphologically regular and irregular forms is not binary, but runs along a continuum. While English (which was the reference language in the first studies on morphology) exhibits a strong dichotomic distinction between morphologically regular and irregular forms, other language systems offer a wider range of distributional properties. An additional set of studies on other Germanic and Romance languages explored different degrees of regularities among morphologically complex words, adding a finer-grained description of morphological variability. Thanks to these contributions, we now know that combinatorial processes (indexed by LAN effects) can be observed not only for overregularization of inflections but even for regular stem violations (Rodríguez-Fornells et al., 2001; cf. Linares et al., 2006). In addition, Bartke et al. (2005) highlighted the fact that the parser is sensitive to probabilistic properties available not only in regular but even in irregular forms, suggesting the presence of a gradient from regular to irregular forms rather than a dichotomy. Similarly, Havas et al. (2012) observed that within the range of derivation violations there is a certain degree of variability that might depend on how productive derivational morphemes are. These observations remind us that dual-route models might offer an oversimplified picture of cognitive processes and encourage us to further explore how the cognitive system deals with the varying degrees of regularity, combinatorial properties, and distributional patterns present in different languages.

Conclusion

In this brief overview, we have summarized electrophysiological findings on morphological analysis in sentence contexts. Results from ERP studies conducted on sentences have mainly proven consistent with those observed in studies on words in isolation, supporting the view that qualitatively distinct processes might be used to analyze regular and irregular forms. However, some important dissimilarities have also emerged between ERP findings for isolated sentences and words. These differences have the potential to inform and guide future research directions. Specifically, neural correlates of morphological-structure-building processes (indexed by LAN effects) and reanalysis (indexed by P600 effects) have more often been reported for words embedded in sentence contexts, suggesting a potential boost of combinatorial processes in more ecological situations of language comprehension. Moreover, using sentence paradigms provides an opportunity to compare the time course of different levels of linguistic analysis and their potential interactions. Finally, expanding the research on morphological processing to a wide range of languages and linguistic contexts enables us to complement existing theoretical models with new testing case scenarios that can refine the theoretical distinction between regular and irregular morphological forms.

References

Allen, M., Badecker, W., & Osterhout, L. (2003). Morphological analysis in sentence processing: An ERP study. *Language and Cognitive Processes*, 18(4), 405–430. doi:10.1080/01690960244000054.

Barber, H., & Carreiras, M. (2005). Grammatical gender and number agreement in Spanish: An ERP comparison. *Journal of Cognitive Neuroscience*, 17(1), 137–153. doi:10.1162/0898929052880101.

Barber, H., Domínguez, A., & de Vega, M. (2002). Human brain potentials indicate morphological decomposition in visual word recognition. *Neuroscience Letters*, 318(3), 149–152. doi:10.1016/S0304-3940(01)02500-9.

Bartke S., Rosler F., Streb J., & Wiese R. (2005). An ERP-study of German "irregular" morphology. *Journal of Neurolinguistics*, 18(1), 29–55. doi:10.1016/j.jneuroling.2004.10.001.

Bölte, J., Jansma, B. M., Zilverstand, A., & Zwitserlood, P. (2009). Derivational morphology approached with event-related potentials. *The Mental Lexicon*, 4(3), 336–353. doi:10.1075/ml.4.3.02bol.

Chomsky, N., & Halle, M. (1968). *The sound pattern of English*. New York: Harper and Row.

Clahsen, H. (1999). Lexical entries and rules of language: A multidisciplinary study of German inflection. *Behavioral and Brain Sciences*, 22(6), 991–1060. doi:10.1017/s0140525x99002228.

De Vega, M., Urrutia, M., & Dominguez, A. (2010). Tracking lexical and syntactic processes of verb morphology with ERP. *Journal of Neurolinguistics*, 23(4), 400–415. doi:10.1016/j.jneuroling.2010.03.003.

Degno, F., Loberg, O., Zang, C., Zhang, M., Donnelly, N., & Liversedge, S. P. (2019). Parafoveal previews and lexical frequency in natural reading: Evidence from eye movements and fixation-related potentials. *Journal of Experimental Psychology: General*, 148(3), 453–474. doi:10.1037/xge0000494.

Dimigen, O., & Ehinger, B. V. (2021). Regression-based analysis of combined EEG and eye-tracking data: Theory and applications. *Journal of Vision*, 21(1), 1–30. doi:10.1167/jov.21.1.3.

Domínguez, A., De Vega, M., & Barber, H. (2004). Event-related brain potentials elicited by morphological, homographic, orthographic and semantic priming. *Journal of Cognitive Neuroscience*, 16(4), 598–608. doi:10.1162/089892904323057326.

Friederici, A. (2002). Towards a neural basis of auditory sentence processing. *Trends in Cognitive Sciences*, 6(2), 78–84. doi:10.1016/s1364-6613(00)01839-8.

Gross, M., Say, T., Kleingers, M., Münte, T., & Clahsen, H. (1998). Human brain potentials to violations in morphologically complex Italian words. *Neuroscience Letters*, 241(2–3), 83–86. doi:10.1016/s0304-3940(97)00971-3.

Halle, M., & Marantz, A. (1993). Distributed morphology and the pieces of inflection. In K. Hale, & S. J. Keyser (Eds.), *The view from building 20* (pp. 111–176). Cambridge, MA: MIT Press.

Havas, V., Rodríguez-Fornells, A., & Clahsen, H. (2012). Brain potentials for derivational morphology: An ERP study of deadjectival nominalizations in Spanish. *Brain and Language*, 120(3), 332–344. doi:10.1016/j.bandl.2011.10.008.

Hoen, M., & Dominey, P. F. (2000). ERP analysis of cognitive sequencing: A left anterior negativity related to structural transformation processing. *NeuroReport*, 11(14), 3187–3191. doi:10.1097/00001756-200009280-00028.

Joanisse, M., & Seidenberg, M. (1999). Impairments in verb morphology after brain injury: A connectionist model. *Proceedings of the National Academy of Sciences*, 96(13), 7592–7597. doi:10.1073/pnas.96.13.7592.

Kutas, M., & Federmeier, K. D. (2011). Thirty years and counting: Finding meaning in the N400 component of the event-related brain potential (ERP). *Annual Review of Psychology*, 62, 621–647. doi:10.1146/annurev.psych.093008.131123.

Lavric, A., Clapp, A., & Rastle, K. (2007). ERP evidence of morphological analysis from orthography: A masked priming study. *Journal of Cognitive Neuroscience*, 19(5), 866–877. doi:10.1162/jocn.2007.19.5.866.

Leinonen, A., Brattico, P., Järvenpää, M., & Krause, C. M. (2008). Event-related potential (ERP) responses to violations of inflectional and derivational rules of Finnish. *Brain Research*, 1218, 181–193.

Leminen, A., Jakonen, S., Leminen, M., Mäkelä, J. P., & Lehtonen, M. (2016). Neural mechanisms underlying word- and phrase-level morphological parsing. *Journal of Neurolinguistics*, 38, 26–41. doi:10.1016/j.jneuroling.2015.10.003.

Linares, R.E., Rodríguez-Fornells, A., Clahsen, H. (2006). Stem allomorphy in the Spanish mental lexicon: Evidence from behavioral and ERP experiments. *Brain and Language*, 97(1), 110–120. doi:10.1016/j.bandl.2005.08.008.

Lück, M., Hahne, A., & Clahsen, H. (2006). Brain potentials to morphologically complex words during listening. *Brain Research*, 1077(1), 144–152. doi:10.1016/j.brainres.2006.01.030.

Marslen-Wilson, W., & Tyler, L. (1997). Dissociating types of mental computation. *Nature*, 387, 592–594. doi:10.1038/42456.

Marslen-Wilson, W., & Tyler, L. (1998). Rules, representations, and the English past tense. *Trends in Cognitive Science*, 2(11), 428–435. doi:10.1016/s1364-6613(98)01239-x.

McClelland, J. L., & Patterson, K. (2002). Rules or connections in past-tense inflections: What does the evidence rule out? *Trends in Cognitive Sciences*, 6(11), 465–472. doi:10.1016/s1364-6613(02)01993-9.

Molinaro, N., Barber, H. A., & Carreiras, M. (2011). Grammatical agreement processing in reading: ERP findings and future directions. *Cortex*, 47(8), 908–930. doi:10.1016/j.cortex.2011.02.019.

Molinaro, N., Carreiras, M., & Dunabeitia, J. A. (2012). Semantic combinatorial processing of non-anomalous expressions. *NeuroImage*, 59(4), 3488–3501. doi:10.1016/j.neuroimage.2011.11.009.

Morris, J., Frank, T., Grainger, J., & Holcomb, P. J. (2007). Semantic transparency and masked morphological priming: An ERP investigation. *Psychophysiology*, 44(4), 506–521. doi:10.1111/j.1469-8986.2007.00538.x.

Morris, J., Grainger, J., & Holcomb, P. J. (2008). An electrophysiological investigation of early effects of masked morphological priming. *Language and Cognitive Processes*, 23(7), 1021–1056. doi:10.1080/01690960802299386.

Morris, J., & Holcomb, P. J. (2005). Event-related potentials to violations of inflectional verb morphology in English . *Cognitive Brain Research*, 25(3), 963–981. doi:10.1016/j.cogbrainres.2005.09.021.

Münte, T. F., Say, T., Clahsen, H., Schiltz, K., & Kutas, M. (1999). Decomposition of morphologically complex words in English: Evidence from event-related brain potentials. *Cognitive Brain Research*, 7(3), 241–253. doi:10.1016/S0926-6410(98)00028-7.

Newman, A. J., Ullman, M. T., Pancheva, R., Waligura, D. L., & Neville, H. J. (2007). An ERP study of regular and irregular English past tense inflection. *NeuroImage*, 34(1), 435–445. doi:10.1016/j.neuroimage.2006.09.007.

Osterhout, L., & Mobley, L. (1995). Event-related brain potentials elicited by failure to agree. *Journal of Memory and Language*, 34(6), 739–773. doi:10.1006/jmla.1995.1033.

Penke, M., Weyerts, H., Gross, M., Zander, E., Münte, T. F., & Clahsen, H. (1997). How the brain processes complex words: An event-related potential study of German verb inflections. *Cognitive Brain Research*, 6(1), 37–52. doi:10.1016/s0926-6410(97)00012-8.

Pinker, S. (1991). Rules of language. *Science*, 253(5019), 530–535. doi:10.1126/science.1857983.

Pinker, S. (1999). *Words and rules: The ingredients of language*. New York: Basic Books.

Pinker, S., & Prince, A. (1994). Regular and irregular morphology and the psychological status of rules of grammar. In S. D. Lima, R. L. Corrigan, & G. K. Iverson (Eds.), *The reality of linguistic rules* (pp. 321–351). Philadelphia: Benjamins.

Pinker, S., & Ullman, M. (2002). The past and future of the past tense. *Trends in Cognitive Sciences*, 6(11), 456–462. doi:10.1016/S1364-6613(02)01990-3.

Rastle, K., Lavric, A., Elchlepp, H., & Crepaldi, D. (2015). Processing differences across regular and irregular inflections revealed through ERPs. *Journal of Experimental Psychology: Human Perception & Performance*, 41(3), 747–760. doi:10.1037/a0039150.

Rodríguez-Fornells, A., Clahsen, H., Lleó, C., Zaake, W., & Münte, T. F. (2001). Event-related brain responses to morphological violations in Catalan. *Cognitive Brain Research*, 11 (1), 47–58. doi:10.1016/S0926-6410(00)00063-X.

Rueckl, J., Mikolinski, M., Raveh, M., Miner, C., & Mars, F. (1997). Morphological priming, fragment completion, and connectionist networks. *Journal of Memory and Language*, 36(3), 382–405. doi:10.1006/jmla.1996.2489.

Rumelhart, D. E. & McClelland, J. L. (1986). On learning the past tenses of English verbs. In J. L. McClelland, D. E. Rumelhart & the PDP Research Group (Eds.), *Parallel distributed processing*. Vol. 2 (pp. 216–271). Cambridge, MA: MIT Press.

Schremm, A., Novén, M., Horne, M., & Roll, M. (2019). Brain responses to morphologically complex verbs: An electrophysiological study of Swedish regular and irregular past tense forms. *Journal of Neurolinguistics*, 51, 76–83. doi:10.1016/j.jneuroling.2019.01.006.

Sonnenstuhl, I., Eisenbeiss, S., & Clahsen, H. (1999). Morphological priming in the German mental lexicon. *Cognition*, 72(3), 203–236. doi:10.1016/s0010-0277(99)00033-5.

Stockall, L., & Marantz, A. (2006). A single route, full decomposition model of morphological complexity: MEG evidence. *The Mental Lexicon*, 1(1): 85–123. doi:10.1075/ml.1.1.07sto.

Ullman, M. (1999). Acceptability ratings of regular and irregular past-tense forms: Evidence for a dual-system model of language from word frequency and phonological neighborhood effects. *Language and Cognitive Processes*, 14(1), 47–67. doi:10.1080/016909699386374.

Ullman, M. (2001). A neurocognitive perspective on language: The declarative/procedural model. *Nature Reviews Neuroscience*, 2, 717–726. doi:10.1038/35094573.

Ullman, M (2004). Contributions of memory circuits to language: The declarative/procedural model. *Cognition*, 92(1–2), 231–270. doi:10.1016/j.cognition.2003.10.008.

Weiss, B., Dreyer, F., Fonteneau, E., van Casteren, M., and Hauk, O., (2021). Investigating brain mechanisms underlying natural reading by co-registering eye tracking with combined EEG and MEG. *bioRXiv*. doi:10.1101/2021.07.09.451139.

Weyerts, H., Penke, M., Dohrn, U., Clahsen, H., & Münte, T. (1997). Brain potentials indicate differences between regular and irregular German noun plurals. *NeuroReport*, 8(4), 957–962. doi:10.1097/00001756-199703030-00028.

9

THE IMPORTANCE OF EYE MOVEMENT RESEARCH FOR GAINING INSIGHT INTO MORPHOLOGICAL PROCESSING

Raymond Bertram and Jukka Hyönä

Introduction

In the current chapter, we outline contributions eye movement research has made to the field of morphological processing. After describing some basic characteristics of eye movements (Section 1), we discuss the time course of morphological processing (Section 2), the role of context in morphological processing (Section 3), and individual differences in morphological skills (Section 4). We focus mostly on recent studies, as earlier studies have been covered in previous review articles (e.g., Bertram, 2011; Hyönä, 2015). In the time-course section, we review recent evidence for parafoveal morphological processing and discuss how different eye-tracking measures can be used to assess the early vs. late effects of morphology. In the context section, we discuss studies comparing the processing of complex words in isolation and in context. In the final section, we explore how individual differences in morphological skills are related to the time course of morphological processing.

Basic Eye Movement Characteristics

In Figure 9.1, an eye movement record of a hypothetical adult reader is presented for a Finnish sentence. In the figure, circles denote *fixations*, moments of relative standstills of the eyes, and yellow arrows denote *saccades*, jumps of the eye from one location to another. A proficient adult reader of an alphabetic language like Finnish spends typically around 200–250 ms per fixation, which amounts to 4–5 fixations per second. Other typical features of the eye movement record include the skipping of short words (here *ei* "not"), occasional regressions (indicated by yellow arrows pointing backwards; for instance, from *kielissä* "in the language" to *edes* "even"), and multiple fixations on longer words (here on *aliarvioida* "underestimate" and *arvoituksellisimmissakaan* "not even in the most mysterious"). The fourth word (*pitäisi* "should") is indicated as the

DOI: 10.4324/9781003159759-9

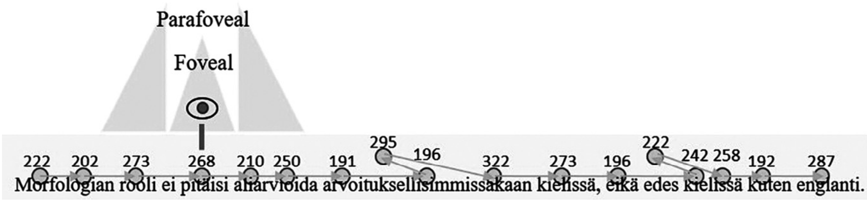

FIGURE 9.1.

currently fixated word and falls therefore within the foveal area. This foveal area with high visual acuity is about 2 degrees around the fixation and typically amounts to 3–4 characters on each side of the fixation. A reader of reading a script written from left to right also extracts information from the parafoveal area to the right of the fixation. In the example, this implies that the reader extracts information from the word *aliarvioida* while fixating on *pitäisi*. To bring in the morphological perspective, one may wonder whether this parafoveally extracted information extends to the morphological level—that is, whether a reader would parafoveally analyze the morphological structure of *aliarvioida*, which consists of a prefix *ali* "under" and a verb stem *arvioida* "estimate." This is exactly what has been done in studies discussed in Section 2.

The eye movement record yields several measures that inform about different stages of morphological and lexical processing. In the case of *aliarvioida* in Figure 9.1, one may consider *first fixation duration* (here 210 ms) as a reflection of early stages of word processing and *gaze duration* as a reflection of processing the whole word during the first pass (here 210 + 250 = 460 ms). First fixation duration even more reliably indexes the early stages of word processing when it is the first of multiple fixations (e.g., Marelli & Luzzatti, 2012). Durations of fixations on morphological constituents may be considered as reflections of constituent processing time (here 210 ms on *ali*- and 250 ms on *arvioida*). The eye fixations on *kielissä* allow us to illustrate a measure named *selective regression path duration* which informs how well a word is integrated in the sentence. It is the summed duration of all fixations on the word before it is exited to the right (here 242 + 258 = 500 ms). This can also or even more accurately be reflected by the *probability of regression from a word. This holds also for regression time*, the time spent on a word after being regressed to (here 222 ms on the word *edes*), which is naturally related to the *probability of regressing to a word*. Both measures can be informative with respect to how well morphological structure is digested in the first pass. That is, multi-morphemic words (e.g. *arvoituksellisimmissakaan*) may require regressive fixations due to incomplete morphological analysis. *Total fixation duration* is the summed duration of all fixations on a word (for *arvoituksellisimmissakaan*, this is 191 + 196 + 295 + 322 = 1,004 ms) and reflects global processing difficulty. Fixation locations can also inform about morphological processing; for instance, initial fixation location can reflect whether morphological analysis has taken place parafoveally. Finally, the number of fixations on a word strongly correlates with gaze or total duration, so they typically do not provide additional insights. The relation of some of these measures with the time course of morphological processing is worked out in Section 2.

The Time Course of Morphological Processing

Extraction of Parafoveal Morphological Information

The eye-tracking method has been applied to study whether readers can process morphological information parafoveally. Studies considering initial fixation location on the target examine whether saccade programming is affected by the morphological structure of the to-be-fixated word. In gaze-contingent display change studies (Rayner, 1975), the parafoveal preview of the target word is manipulated so that the relevant morphological information is or is not available parafoveally. In the latter case, the previewed word is changed to its intended form during the saccade toward it. Thus, upon fixation the reader always perceives the word in its correct form. Due to saccadic suppression, readers typically do not perceive the actual display change. If they do, the preview effect may increase in size, but cannot solely be explained by change perception (Slattery et al., 2011).

Yan et al. (2014) observed an effect of morphological structure of the parafoveal word on initial fixation location in two experiments conducted in Uyghur – a morphologically productive, alphabetic language belonging to the Turkic language family. They found that the initial fixation landed closer to the word beginning for morphologically complex words (stem + two inflections; Exp. 2) than that for monomorphemic words. Hyönä et al. (2018) replicated the effect for Finnish. For both studies, the respective authors argued that perceiving a morphologically complex word in the parafovea triggers a saccade closer to the word beginning.

In a follow-up study using the display change paradigm, Hyönä et al. (2021) investigated the role of the stem in parafoveal morphological extraction. They contrasted the no-change preview condition to a condition where the suffix information (3–4 letters) in the morphologically complex words was denied by replacing the suffix by other letters not forming a morpheme; for the monomorphemic targets, the word-final letters were replaced with other letters as well. Consequently, in the change condition the word stem was parafoveally available for the suffixed but not for the monomorphemic words. The observed initial fixation effects were modified by the preview time (the duration of fixation preceding the target fixation) and by the distance from which the saccade was launched. For near launch sites, the morphological effect observed by Hyönä et al. (2018) – initial fixations closer to the word beginning for suffixed words – was replicated for the no-change condition. In the change condition, an analogous pattern was obtained for far launch sites. As suffix information was denied in this condition, the effect cannot be due to early access of suffix information; instead, it must reflect parafoveal access of the word stem. This result is compatible with the idea of edge-aligned embedded word stems becoming readily activated during lexical access (Beyersmann & Grainger, this volume).

Stoops and Christianson (2017) reported further evidence for parafoveal morphological processing using the display change paradigm. They examined parafoveal suffix (case-marking in nouns) processing of 5-letter Russian nouns using three parafoveal preview conditions: (a) an identical condition where the noun following the verb appeared in the nominal case, denoting sentence subject; (b) a condition where the target appeared parafoveally in the accusative case, denoting sentence object; and (c) a nonword condition where case inflection was replaced with a letter making the preview a nonword. They observed that gaze duration on the target was longer in the (b) condition than in the (a) condition. This parafoveal preview cost demonstrates that inflectional morphology can be processed parafoveally. The result is interpreted as a syntactic interference effect of the integration of the target noun into the sentence structure. Stoops and Christianson (2019) replicated the effect with longer nouns (on average 13 letters).

Mousikou et al. (2020) used a variant of the display change paradigm to examine the parafoveal processing of participle (*abbauen*) and prefixed (*bebauen*) verbs in German. Participles may be free-standing, as they can be separated from the verb, whereas prefixes are always bound to the stem. The parafoveal preview was manipulated by deleting the first letter of the verb stem so that the participle and the prefix stood out as separate visual elements (*ab auen* vs. *be auen*). Both preview conditions produced longer gaze durations than the identical condition, but more importantly they did not differ from each other. The finding is interpreted to reflect that both verb types are highly productive in German. Thus, frequent exposure to these morphological structures may have led to similar morphologically structured mental representations and similar parafoveal preview processing for both verb types.

Hyönä et al. (2021) also analyzed fixation durations as a function of parafoveal preview. They observed that the morphological effect (longer gaze durations on suffixed than monomorphemic words) became stronger with longer parafoveal preview times. Moreover, the effect of launch site was observed for monomorphemic (longer gaze durations for far than near launch sites) but not for suffixed words. The effect indicates that short stems of suffixed words can be perceived even from a far distance, but long stems of monomorphemic words cannot. Thus, also these effects support the view that embedded stems of suffixed words can be parafoveally accessed (Beyersmann & Grainger, this volume).

However, a recent study of Dann et al. (2021) challenges the embedded stem view by demonstrating that the stems of suffixed words can be parafoveally perceived, but only when paired with a genuine suffix. More specifically, they found similar first and single fixation durations for suffixed words (*stressful*) in the case of an identical parafoveal preview and in the case of a morphologically decomposable nonword preview (*stressary*), but slower durations when the preview contained a non-suffix (*stressard*). For prefixed words, there seemed to be no stem extraction at all, as here parafoveal nonwords with (*pretrust*) and without (*whitrust*) a prefix led to longer durations than an identical prime. Initial landing position was not affected by the type of morphological preview, neither for the prefixed nor for the suffixed words. It is noteworthy that the initial fixation location effect was not found in English, even though it did appear in morphologically richer languages like Uyghur and Finnish.

Finally, Cutter et al. (2014) investigated the parafoveal processing of spaced compound words in English (*teddy bear*). They manipulated the parafoveal availability of both the first and second constituent. The boundary was placed to the left of the first constituent; in the change condition, either the first constituent, second constituent, or both constituents were replaced with a nonword. Typically, little information is extracted from a word located two words to the right from the fixated word, but Cutter et al. (2014) reasoned that if subsequent words are linguistically unified—as is the case with spaced compound words—processing may stretch further into the parafovea. If this is the case, there should be a preview benefit for the second constituent (shorter fixation times in the identical word condition than in the nonword condition) when the first constituent is parafoveally available. This was exactly what they found.

The reviewed studies conducted in alphabetic languages (German, Russian, Finnish, Uyghur, English) demonstrate that both inflectional suffixes and word stems of derived words can be parafoveally accessed. In other words, the results point to genuine parafoveal analysis of morphologically complex words; (however, see Dann et al., 2021). For spaced English compounds, the parafoveal processing of the first constituent triggers the processing of the second constituent, which also points to parafoveal morphological analysis. The results stand in contrast with earlier studies on alphabetic languages (English and Finnish: Bertram & Hyönä, 2007; Inhoff, 1989; Juhasz et al., 2008; Kambe, 2004), but are in line with parafoveal morphological processing results obtained for visually more condensed scripts (Hebrew: Deutsch et al., 2003; Chinese: Yen et al., 2008: Korean: Kim et al., 2012). We suspect that the results for condensed scripts are robust, and that increased statistical power in recent studies (more participants and items) and more sensitive statistical methods have now exposed the more subtle parafoveal morphological effects in alphabetic scripts as well, most prominently in morphologically rich languages.

Morphological Effects during and after Foveal Processing

For morphological processing models, it has been particularly important to determine at what time point morphological effects appear. Below, we report the findings of studies that exemplify how eye-tracking measures can be used to assess different stages of morphological processing once a word is fixated.

Velan et al. (2013) investigated the importance of the consonantal root in lexical processing in Hebrew and made use of the transposed letter paradigm. They compared the transposition of letters in Semitic words (e.g., *maxsom*, "barrier," derived from the root x.s.m and the word pattern /maC1C2oC3) and non-Semitic words (e.g., *ʔagartal* "vase," Persian origin), which has a concatenated rather than a root-vowel-pattern structure. They showed that, compared to unchanged conditions, transposing consonantal root letters in Semitic words is much more harmful than transposing letters in non-Semitic words. Moreover, the effect for Semitic words already emerged in first fixation duration, whereas for non-Semitic words it emerged in gaze duration only. This implies that Hebrew readers can differentiate between word types at an early stage and that there is an immediate quest for detecting the root in Semitic words.

Schmidtke and Kuperman (2019) and Schmidtke et al. (2017) demonstrated that a statistical technique named "survival analysis" even allows the assessment of processes within the first fixation duration by inspecting divergence points in the duration distributions for different levels of a variable (e.g., high vs. low stem frequency). They investigated whether processing derivations can be explained by a *form-then-meaning* (Meunier & Longtin, 2007; Rastle et al., 2004; Taft, 2004) or alternatively by a *form-and-meaning* (Feldman et al., 2015) account. The *form-then-meaning* account holds that the first stage of complex-word processing is concerned with morpho-orthographic segmentation leading to morpheme access without any influence of whole-word properties. *Form-and-meaning* accounts posit that complex-word recognition involves immediate access to whole-word properties alongside morpho-orthographic features. Schmidtke et al. (2017) used a large set of variables that were either morpheme-based (e.g., stem frequency, suffix productivity) or word-based (e.g., surface frequency, word length). They found that word-based effects—especially surface frequency—either preceded or emerged simultaneously with morpho-orthographic effects, lending support to the *form-and-meaning* account. For most variables, the divergence points were between 140 ms and 160 ms, which presumably is the upper limit as to when these variables exert an effect.

The influence of morphological structure on the processing of words may not only be present in first-pass reading, but may linger on. For instance, Cohen and Staub (2014) showed that difficult-to-interpret novel compounds (*dictionary treatment*) in comparison to more insightful novel compounds (*torture treatment*) elicit longer first-pass durations on the head noun (*treatment*), independent of the preceding context being supportive or not. However, later processing measures on the word following the target compound showed clear benefits of a preceding supportive context specifying the meaning of the difficult novel compounds—that is, the supportive context elicited shorter fixation durations and fewer regressions on the subsequent word than the neutral context. This is interpreted to reflect the relative difficulty readers have in integrating novel complex words in the sentence representation.

A delayed effect of morphological structure was also reported by Schmidtke at al. (2018), who found different semantic transparency effects during compound processing in late eye movement measures as a function of reading experience. Less reading experience led to higher regression probability and longer total fixation time for transparent compounds vs. opaque compounds. This shows that settling in on a meaning of a transparent compound that fits the sentence representation requires practice. Together, the above results show that morphosemantic effects may appear on the level of sentence integration that can be captured by late eye-movement measures reflecting delayed processing.

The Role of Context in Morphological Processing

Word recognition times in single-word studies are notably longer than those in sentence-context studies as measured by eye movements. Moreover, naming and lexical decision times correlate better with each other than with eye movement measures when the same words are presented in context (Kuperman et al., 2013). This indicates that processing words in isolation reflects partly different cognitive processes than processing words in context. Arguably, studying word processing in context is ecologically more valid, as it typically implies lexical access (unlike naming) but does not involve a decision component (unlike lexical decision) (e.g., Mousikou et al., 2020). Yet, the vast majority of morphological processing studies are single-word studies. Context nevertheless may affect processing morphologically complex words. Here, we review a few studies in which the impact of context was assessed by comparing single-word studies with context studies.

Deutsch et al. (2018) used the fast priming paradigm (Sereno & Rayner, 1992)—a version of the display change paradigm—to study the role of nominal vowel patterns in processing Hebrew derivations in context. In this paradigm, the target word is initially replaced with a random letter string. After the eyes cross an invisible boundary located to the left of the target, the mask is replaced with a prime presented for a short period (here 32 or 41 ms) followed by the target word. In the non-concatenated morphology of Hebrew, words consist of consonantal roots intertwined with vowel patterns. Single-word masked priming studies have consistently shown effects of consonant root but no vowel pattern effects. This has led to the conclusion that the Hebrew mental lexicon is organized and accessed via roots (e.g., Deutsch & Frost, 2003). However, the fast priming context study of Deutsch et al. (2018) did show priming effects for nominal vowel patterns starting to emerge in first fixation duration and clearly significant in gaze duration; this implies that vowel patterns do play a role in Hebrew lexical access after all. Deutsch et al. (2018) ascribe the discrepancy between the masked and fast priming studies to presenting complex words in isolation vs. presenting complex words in context. One possibility is that the main functions of vowel patterns—determining the word's morphosyntactic characteristics and vocalic and metrical structure—are only functional in context. In other words, the vowel pattern may become stranded in isolation and not actively participate in lexical access.

Luke and Christianson (2015) investigated the role of semantic and syntactic context in processing English inflectional suffixes by means of the transposed letter paradigm. Earlier studies showed that letter transpositions (JUDGE—JUGDE) only lead to small processing delays. Luke and Christianson (2015) manipulated the expectation of inflectional suffixes by pitting a leading syntactic context (The man would have *burned*…, where the suffix *–ed* can be predicted by the context) against a context free of syntactic expectations (At the hospital, the *burned* patient …). They found greater and earlier disruption from cross-morpheme letter transpositions (*burend*) in the leading context than in the neutral syntactic context. In contrast, semantic predictability did not affect the transposition effects. The results implicate morphosyntactic top-down effects on inflectional processing, which may be quite abundant in English. The authors therefore warn researchers to be cautious in relying exclusively on single-word methods when investigating inflectional morphology. As derivations and compounds are not so much bound to syntactic constraints, they suspect them to be less susceptible to top-down influences.

Mousikou and Schroeder (2019) studied the processing of German derivations using a single-word and a sentence-reading paradigm. For sentence reading, they used fast priming combined with eye-tracking, and for single-word reading they used equivalent masked priming. There were five types of primes for each target word. For example, for the prefixed word *vorsagen*, there was an identical prime, a pseudomorphological prime (*hinsagen*, including two morphemes forming a non-existing word), a nonmorphological prime (*taksagen*, with the nonword *tak*), a word control (*hinsicht*), and a nonword control (*taksicht*). The nonmorphological and pseudomorphological condition produced faster gaze durations than the word and nonword controls, but did not differ from each other for both prefixed and suffixed derivations. The results support the view that embedded stems are activated early during lexical access regardless of whether they are accompanied by an affix or not (see Beyersmann & Grainger, this volume). Moreover, as the results were the same in the fast and masked priming experiments, it was concluded that single-word studies may tap into lexical processes that are similar to those during sentence reading. The latter conclusion accords with the notion of Luke and Christianson (2015) that derivations are not syntactically predictable. In Mousikou and Schroeder (2019), this is clearly the case. For instance, in the experimental sentence *Nadine sollte das Buch vorlesen*, the prefixed target word *vorlesen* ("read aloud") could easily be replaced by the monomorphemic variant *lesen* ("read"). Even though the explanation for similar results across paradigms in this study could be ascribed to derivations being relatively free of syntactic constraints, it could also be ascribed—at least partly—to the context paradigm—that is, the fast priming paradigm does not allow one to extract information parafoveally. Thus, readers could not benefit from possible parafoveal extraction of morphological information, as would have been the case in normal reading.

Schmidtke et al. (2017) extracted lexical decision data on derivations from the English Lexicon Project (Balota et al., 2007) with the results of eye-tracking experiments where derived words were inserted in sentence context. The selected suffixes and words were similar but not identical across paradigms. They found that word-based effects either preceded or emerged simultaneously with morpho-orthographic effects, lending support to the *form-and-meaning* account. Minor differences emerged between paradigms, but all in all the time course by which all variables exerted their effects was within the same time range (for eye movements 114 ms, for lexical decision 133 ms). This suggests that context has a relatively small influence on processing derived words. The same was found for compound-word processing in Italian (Marelli & Luzzatti, 2012). Experimental evidence thus suggests that processing derivations and compounds is less affected by context than processing inflections.

It is noteworthy that in most context studies the context is typically quite minimal, usually consisting of a sentence fragment. However, evidence suggests that processing words in larger contexts may be different. Radach et al. (2008) showed that gaze durations were shorter but total fixation times longer for words in passage-embedded sentences compared to words in isolated sentences. Kuperman et al. (2013) found that word processing in isolation was more similar to word processing in single sentences than in sentences embedded in larger contexts. Also the frequency effect was larger in isolated passages than it was in passage-embedded sentences. Kuperman et al. (2013) argue that in isolated-sentence studies words are typically less predictable, making them more comparable to isolated-word studies than to reading in larger contexts, where words are often more predictable. It is an open question as to how morphologically complex words will be processed in larger contexts. It is for instance conceivable that higher predictability would lead to more extensive parafoveal morphological processing. Also repetition of morphologically complex words is likely to occur in larger context, which may alter the way they are processed.

Individual Differences in Morphological Skills

Morphological skills are considered to be an important component of general language proficiency. Thus, the development of morphological skills has been investigated among developing readers, second language learners, and special populations. Below, we review a few eye movement studies that investigate whether morphological structure is employed in lexical access and whether morphosyntactic cues, which may be rather subtle, are activated—and if so, at which time point.

Häikiö and Vainio (2018) investigated whether morphemes are functional processing units in early Finnish reading development. They embedded target words in sentences with syllable-congruent (*ta-los-sa* "in the house"; the stem *talo* "house" and the inessive suffix *–ssa* "in") or morpheme-congruent hyphenation (*talo-ssa*). Despite Finnish ABC-books using syllable-congruent hyphenation, the results indicated more efficient processing for morpheme-congruent hyphenation. The results suggest that Finnish readers utilize morpheme-level information already during the first grade. Cholewa et al. (2019) showed that German third- and fourth-grade children are able to make use of morphosyntactic predictability. They showed that children made use of gender cues (*ein*$^{\mathrm{MASC}}$*vs. eine*$^{\mathrm{FEM}}$) to speed up the processing of upcoming nouns (Teller$^{\mathrm{MASC}}$ vs. Tasse$^{\mathrm{FEM}}$). Breadmore and Carroll (2018) found that in a sentence reading task English early and later elementary school children showed processing delays on morphological overregularizations (*knowed*) in gaze duration and total fixation time, whereas for adults the effect only appeared in total fixation time. These results may indicate that adults are more advanced in morphological analysis than children by initially extracting the necessary morphological information to proceed.

In the realm of second language acquisition, Arslan et al. (2015) used the visual-word paradigm to compare the processing of evidential morphology by native Turkish speakers with that of early (heritage) and late Turkish-German bilinguals. Evidential morphology is marked by different suffixes, depending on whether an action is directly witnessed (somebody drinking a glass of milk) or inferred (seeing an empty glass with white traces). The task was to link the pictures to the spoken utterances. The results showed no difference across groups in response times and proportions of looks to indirect evidentials, but clear advantages for the monolingual group for direct evidentials. Using the same paradigm, Dussias et al. (2013) showed that monolingual and proficient L2 Spanish speakers could make use of the gender information of the articles to speed up object selection. This was not the case for less proficient bilinguals. Similar visual world paradigm studies in L2 German showed that very advanced L2 speakers can reach native-level ability in using predictability related to grammatical gender (e.g., Lemmerth & Hopp, 2019). The role of language proficiency in morphosyntactic processing was also found in a number of reading studies. More specifically, Lim and Christianson (2015) found a delayed effect of subject–verb agreement violations for Korean L2 speakers in comparison to English natives, and Sagarra and Ellis (2013) found that lower-proficiency Spanish L2 speakers needed to regress more than higher-proficiency ones when exposed to tense incongruences (*yesterday he sees*). More eye-tracking studies on morphosyntactic prediction in L2 research are reviewed in Godfroid (2020).

With respect to special populations, Schouwenaars et al. (2019) showed that 7- to 12-year-old German children with cochlear implants required more reanalysis time than normally hearing children to make sense of sentences with the case-marked object in sentence-initial position. Moreover, Hanne et al. (2015) demonstrated that individuals with aphasia successfully use morphological subject–verb agreement or case-marking cues, but the integration of morphological information is delayed in comparison to age-matched controls. Breadmore and Carroll (2018) showed that also dyslexic readers are sensitive to morphological overregularizations.

The studies reviewed in this section show that not being fully proficient in a language is associated with less profound and/or delayed morphological processing. In sum, it is concluded that eye movements can reveal different levels of morphological and morphosyntactic skills in both auditory and visual language comprehension.

Conclusions

We have discussed a number of recent studies to illustrate how eye-tracking can be used to study different aspects of morphological processing. Due to space limitations, we left undiscussed some fields in which morphological processing has recently been studied by eye movements, including vocabulary acquisition (Beyersmann et al., 2020; Binder et al., 2020), linguistic transfer (Bertram & Kuperman, 2020), language development (Alamargot et al., 2015; Silva et al., 2013), autism (Tovar et al., 2015), infant language processing (Ferry et al, 2020), Arabic word processing (Hermena et al., 2019), visual constraints (Amenta et al., 2015; Hyönä et al., 2020; Lázaro et al., 2020), L2 compound processing (Clahsen et al., 2015), compound spelling (Falkauskas & Kuperman, 2015), Chinese compound processing (Drieghe et al., 2018, Shen et al., 2018), and studies testing morphological-processing models (Juhasz, 2018; Kush et al., 2019). Moreover, large eye movement corpora specifically useful for morphological investigations have started to emerge (for morphosyntax, see Luke & Christianson, 2018; for English compounds, see Schmidtke et al., 2020). It is noteworthy that practically all morphological studies deal with the processing of bimorphemic words (but see Miwa et al., 2017), even though in many languages multimorphemic words are very common.

We have argued that the eye-tracking method is especially useful for examining the role of morphological complexity in lexical processing in context, which may differ from processing words in isolation. Moreover, eye-tracking provides insights into the time course of processing, as it yields multiple measures that can be linked to different stages of processing—that is, morphological complexity not only impacts word processing parafoveally and foveally, but it can impact it downstream as well. Especially in the case of limited morphological skills (second language learners, developing readers), the utilization of relevant morphological information is often delayed, possibly leading to problems in language comprehension.

Future eye movement studies in applied domains like second language acquisition or among special populations could extend their scope by not only focusing on morphosyntactic processing, but also on the processing of derivations and compounds. The latter word classes often include relatively low-frequent or novel formations, which will put individuals' morpho-orthographic and morphosemantic skills to the test. Future eye movement studies should also examine to what extent morphological processing theories can be built on single-word studies, as the results of such studies could be compromised for not having the possibility of parafoveal pre-processing and the lack of a syntactically and/or semantically suitable context. However, context studies could also extend their scope by exploring morphological processing in contexts larger than the sentence, as larger contexts may include several cues that could alter the way morphologically complex words are processed. In any case, to study the role of morphology in language processing in a broad context and in a multifaceted way, the use of eye movement research is indispensable.

References

Alamargot, D., Flouret, L., Larocque, D., Caporossi, G., Pontart, V., Paduraru, C., Morisset, P., & Fayol, M. (2015). Successful written subject–verb agreement: An online analysis of the procedure used by students in Grades 3, 5 and 12. *Reading and Writing*, 28(3), 291–312. doi:10.1007/s11145-014-9525-0.

Amenta, S., Marelli, M., & Crepaldi, D. (2015). The fruitless effort of growing a fruitless tree: Early morpho-orthographic and morpho-semantic effects in sentence reading. *Journal of*

Experimental Psychology: Learning, Memory, and Cognition, 41(5), 1587–1596. doi:10.1037/xlm0000104.

Arslan, S., Bastiaanse, R., & Felser, C. (2015). Looking at the evidence in visual world: Eye-movements reveal how bilingual and monolingual Turkish speakers process grammatical evidentiality. *Frontiers in Psychology*, 6, 1387. doi:10.3389/fpsyg.2015.01387.

Balota, D. A., Yap, M. J., Hutchison, K. A., Cortese, M. J., Kessler, B., Loftis, B., Neely, J. H., Nelson, D. L., Simpson, G. B., & Treiman, R. (2007). The English Lexicon Project. *Behavior Research Methods*, 39(3), 445–459. doi:10.3758/BF03193014.

Bertram, R. (2011). Eye movements and morphological processing in reading. *The Mental Lexicon*, 6(1), 83–109. doi:10.1075/ml.6.1.04ber.

Bertram, R., & Hyönä, J. (2007). The interplay between parafoveal preview and morphological Processing in reading. In R. P. G. van Gompel, M. H. Fischer, W. S. Murray, & R. Hill (Eds.), *Eye movements: A window on mind and brain* (pp. 391–407). Amsterdam: Elsevier.

Bertram, R., & Kuperman, V. (2020). The English disease in Finnish compound processing: Backward transfer effects in Finnish–English bilinguals. *Bilingualism: Language and Cognition*, 23(3), 579–590. doi:10.1017/S1366728919000312.

Beyersmann, E., Wegener, S., Nation, K., Prokupzcuk, A., Wang, H.-C., & Castles, A. (2020). Learning morphologically complex spoken words: Orthographic expectations of embedded stems are formed prior to print exposure. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 47(1), 87–98. doi:10.1037/xlm0000808.

Binder, K. S., Tremblay, K. A., & Joseph, A. (2020). Vocabulary accessibility and acquisition: Do you get more from a financestor or a sociophite? *Journal of Research in Reading*, 43(4), 395–416. doi:10.1111/1467-9817.12314.

Breadmore, H. L., & Carroll, J. M. (2018). Sublexical and syntactic processing during reading: Evidence from eye movements of typically developing and dyslexic readers. *Journal of Cognitive Psychology*, 30(2), 177–197. doi:10.1080/20445911.2017.1414222.

Cholewa, J., Neitzel, I., Bürsgens, A., & Günther, T. (2019). Online-processing of grammatical gender in noun-phrase decoding: An eye-tracking study with monolingual German 3rd and 4th graders. *Frontiers in Psychology*, 10, 2586. doi:10.3389/fpsyg.2019.02586.

Clahsen, H., Gerth, S., Heyer, V., & Schott, E. (2015). Morphology constrains native and non-native word formation in different ways: Evidence from plurals inside compounds. *The Mental Lexicon*, 10(1), 53–87. doi:10.1075/ml.10.1.03cla.

Cohen, A. L., & Staub, A. (2014). Online processing of novel noun–noun compounds: Eye movement evidence. *Quarterly Journal of Experimental Psychology*, 67(1), 147–165. doi:10.1080/17470218.2013.796398.

Cutter, M. G., Drieghe, D., & Liversedge, S. P. (2014). Preview benefit in English spaced compounds. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 40(6), 1778–1786. doi:10.1037/xlm0000013.

Dann, K.M, Veldre, A., & Andrews, S. (2021). Morphological preview effects in English are restricted to suffixed words. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 47(8), 1338–1352. doi:10.1037/xlm0001029.

Deutsch, A., & Frost, R. (2003). Lexical organization and lexical access in a non-concatenated morphology: Mapping the mental lexicon. In Y. Shimron (Ed.), *Language processing and acquisition in languages of Semitic, root- based morphology* (pp. 165–186). Amsterdam: John Benjamins.

Deutsch, A., Frost, R., Pelleg, S., Pollatsek, A., & Rayner, K. (2003). Early morphological effects in reading: Evidence from parafoveal preview benefit in Hebrew. *Psychonomic Bulletin & Review*, 10(2), 415–422. doi:10.3758/BF03196500.

Deutsch, A., Velan, H., & Michaly, T. (2018). Decomposition in a non-concatenated morphological structure involves more than just the roots: Evidence from fast priming. *Quarterly Journal of Experimental Psychology*, 71(1), 85–92. doi:10.1080/17470218.2016.1250788.

Drieghe, D., Cui, L., Yan, G., Bai, X., Chi, H., & Liversedge, S. P. (2018). The morphosyntactic structure of compound words influences parafoveal processing in Chinese reading. *Quarterly Journal of Experimental Psychology*, 71(1), 190–197. doi:10.1080/17470218.2017.1307426.

Dussias, P. E., Valdés Kroff, J. R., Guzzardo Tamargo, R. E., & Gerfen, C. (2013). When gender and looking go hand in hand: Grammatical gender processing in L2 Spanish. *Studies in Second Language Acquisition*, 35(2), 353–387. doi:10.1017/S0272263112000915.

Falkauskas, K., & Kuperman, V. (2015). When experience meets language statistics: Individual variability in processing English compound words. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 41(6), 1607–1627. doi:10.1037/xlm0000132.

Feldman, L. B., Milin, P., Cho, K. W., Moscoso del Prado Martín, F., & O'Connor, P. A. (2015). Must analysis of meaning follow analysis of form? A time course analysis. *Frontiers in Human Neuroscience*, 9. doi:10.3389/fnhum.2015.00111.

Ferry, A., Nespor, M., & Mehler, J. (2020). Twelve to 24-month-olds can understand the meaning of morphological regularities in their language. *Developmental Psychology*, 56(1), 40–52. doi:10.1037/dev0000845.

Godfroid, A. (2020). *Eye tracking in second language acquisition and bilingualism: A research synthesis and methodological guide*. New York: Routledge.

Häikiö, T., & Vainio, S. (2018). Syllables and inflectional morphemes in early Finnish readers: Evidence from eye-movements. *Journal of Child Language*, 45(5), 1227–1245. doi:10.1017/S0305000918000132.

Hanne, S., Burchert, F., De Bleser, R., & Vasishth, S. (2015). Sentence comprehension and morphological cues in aphasia: What eye-tracking reveals about integration and prediction. *Journal of Neurolinguistics*, 34, 83–111. doi:10.1016/j.jneuroling.2014.12.003.

Hermena, E. W., Liversedge, S. P., Bouamama, S., & Drieghe, D. (2019). Orthographic and root frequency effects in Arabic: Evidence from eye movements and lexical decision. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 45(5), 934–954. doi:10.1037/xlm0000626.

Hyönä, J. (2015). Are polymorphemic words processed differently from other words during reading? In A. Pollatsek & R. Treiman (Eds.), *The Oxford handbook of reading* (pp. 114–118). New York: Oxford University Press.

Hyönä, J., Heikkilä, T. T., Vainio, S., & Kliegl, R. (2021). Parafoveal access to word stem during reading: An eye movement study. *Cognition*, 208, 104547. doi:10.1016/j.cognition.2020.104547.

Hyönä, J., Pollatsek, A., Koski, M., & Olkoniemi, H. (2020). An eye-tracking study of reading long and short novel and lexicalized compound words. *Journal of Eye Movement Research*, 13(4). doi:10.16910/jemr.13.4.3.

Hyönä, J., Yan, M., & Vainio, S. (2018). Morphological structure influences the initial landing position in words during reading Finnish. *Quarterly Journal of Experimental Psychology*, 71(1), 122–130. doi:10.1080/17470218.2016.1267233.

Inhoff, A. W. (1989). Parafoveal processing of words and saccade computation during eye fixations in reading. *Journal of Experimental Psychology: Human Perception and Performance*, 15 (3), 544–555. doi:10.1037/0096-1523.15.3.544.

Juhasz, B. J. (2018). Experience with compound words influences their processing: An eye movement investigation with English compound words. *Quarterly Journal of Experimental Psychology*, 71(1), 103–112. doi:10.1080/17470218.2016.1253756.

Juhasz, B. J., White, S. J., Liversedge, S. P., & Rayner, K. (2008). Eye movements and the use of parafoveal word length information in reading. *Journal of Experimental Psychology: Human Perception and Performance*, 34(6), 1560–1579. doi:10.1037/a0012319.

Kambe, G. (2004). Parafoveal processing of prefixed words during eye fixations in reading: Evidence against morphological influences on parafoveal preprocessing. *Perception & Psychophysics*, 66(2), 279–292. doi:10.3758/BF03194879.

Kim, Y.-S., Radach, R., & Vorstius, C. (2012). Eye movements and parafoveal processing during reading in Korean. *Reading and Writing*, 25(5), 1053–1078. doi:10.1007/s11145-011-9349-0.

Kush, D., Dillon, B., Eik, R., & Staub, A. (2019). Processing of Norwegian complex verbs: Evidence for early decomposition. *Memory & Cognition*, 47(2), 335–350. doi:10.3758/s13421-018-0870-0.

Kuperman, V., Drieghe, D., Keuleers, E., & Brysbaert, M. (2013). How strongly do word reading times and lexical decision times correlate? Combining data from eye movement corpora and megastudies. *Quarterly Journal of Experimental Psychology*, 66(3), 563–580. doi:10.1080/17470218.2012.658820.

Lázaro, M., Pérez, E., & Martínez, R. (2020). Perceptual salience of derivational suffixes in visual word recognition. *Scandinavian Journal of Psychology*, 61(3), 348–360. doi:10.1111/sjop.12617.

Lemmerth, N., & Hopp, H. (2019). Gender processing in simultaneous and successive bilingual children: Cross-linguistic lexical and syntactic influences. *Language Acquisition*, 26(1), 21–45. doi:10.1080/10489223.2017.1391815.

Lim, J. H., & Christianson, K. (2015). Second language sensitivity to agreement errors: Evidence from eye movements during comprehension and translation. *Applied Psycholinguistics*, 36(6), 1283–1315. doi:10.1017/S0142716414000290.

Luke, S. G., & Christianson, K. (2015). Predicting inflectional morphology from context. *Language, Cognition and Neuroscience*, 30(6), 735–748. https://doi.org/10.1080/23273798.2015.1009918.

Luke, S. G., & Christianson, K. (2018). The Provo Corpus: A large eye-tracking corpus with predictability norms. *Behavior Research Methods*, 50(2), 826–833. doi:10.3758/s13428-017-0908-4.

Marelli, M., & Luzzatti, C. (2012). Frequency effects in the processing of Italian nominal compounds: Modulation of headedness and semantic transparency. *Journal of Memory and Language*, 66(4), 644–664. doi:10.1016/j.jml.2012.01.003.

Meunier, F., & Longtin, C.-M. (2007). Morphological decomposition and semantic integration in word processing. *Journal of Memory and Language*, 56(4), 457–471. doi:10.1016/j.jml.2006.11.005.

Miwa, K., Libben, G., & Ikemoto, Y. (2017). Visual trimorphemic compound recognition in a morphographic script. *Language, Cognition and Neuroscience*, 32(1), 1–20. doi:10.1080/23273798.2016.1205204.

Mousikou, P., Nüesch, L., Hasenäcker, J., & Schroeder, S. (2020). Reading morphologically complex words in German: The case of particle and prefixed verbs. *Language, Cognition and Neuroscience*, 36(2),255–268. doi:10.1080/23273798.2020.1810291.

Mousikou, P., & Schroeder, S. (2019). Morphological processing in single-word and sentence reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 45(5), 881–903. doi:10.1037/xlm0000619.

Radach, R., Huestegge, L., & Reilly, R. (2008). The role of global top-down factors in local eye-movement control in reading. *Psychological Research*, 72(6), 675–688. doi:10.1007/s00426-008-0173-3.

Rastle, K., Davis, M. H., & New, B. (2004). The broth in my brother's brothel: Morpho-orthographic segmentation in visual word recognition. *Psychonomic Bulletin & Review*, 11(6), 1090–1098. doi:10.3758/BF03196742.

Rayner, K. (1975). The perceptual span and peripheral cues in reading. *Cognitive Psychology*, 7(1), 65–81. doi:10.1016/0010-0285(75)90005–90005.

Sagarra, N., & Ellis, N. C. (2013). From seeing adverbs to seeing verbal morphology: Language experience and adult acquisition of L2 tense. *Studies in Second Language Acquisition*, 35(2), 261–290. doi:10.1017/S0272263112000885.

Schmidtke, D., & Kuperman, V. (2019). A paradox of apparent brainless behavior: The time-course of compound word recognition. *Cortex*, 116, 250–267. doi:10.1016/j.cortex.2018.07.003.

Schmidtke, D., Matsuki, K., & Kuperman, V. (2017). Surviving blind decomposition: A distributional analysis of the time-course of complex word recognition. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 43(11), 1793–1820. doi:10.1037/xlm0000411.

Schmidtke, D., Van Dyke, J. A., & Kuperman, V. (2018). Individual variability in the semantic processing of English compound words. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 44(3), 421–439. doi:10.1037/xlm0000442.

Schmidtke, D., Van Dyke, J. A., & Kuperman, V. (2020). CompLex: An eye-movement database of compound word reading in English. *Behavior Research Methods*, 53, 55–77. doi:10.3758/s13428-020-01397-1.

Schouwenaars, A., Finke, M., Hendriks, P., & Ruigendijk, E. (2019). Which questions do children with cochlear implants understand? An eye-tracking study. *Journal of Speech, Language, and Hearing Research*, 62(2), 387–409. doi:10.1044/2018_JSLHR-H-17-0310.

Sereno, S. C., & Rayner, K. (1992). Fast priming during eye fixations in reading. *Journal of Experimental Psychology: Human Perception and Performance*, 18(1), 173–184. doi:10.1037/0096-1523.18.1.173.

Shen, W., Li, X., & Pollatsek, A. (2018). The processing of Chinese compound words with ambiguous morphemes in sentence context. *Quarterly Journal of Experimental Psychology*, 71(1), 131–139. doi:10.1080/17470218.2016.1270975.

Silva, R., Gerth, S., & Clahsen, H. (2013). Morphological constraints in children's spoken language comprehension: A visual world study of plurals inside compounds in English. *Cognition*, 129(2), 457–469. doi:10.1016/j.cognition.2013.08.003.

Slattery, T. J., Angele, B., & Rayner, K. (2011) Eye movements and display change detection during reading. *Journal of Experimental Psychology: Human Perception and Performance* 37(6), 1924–1938. doi:10.1037/a0024322.

Stoops, A., & Christianson, K. (2017). Parafoveal processing of inflectional morphology on Russian nouns. *Journal of Cognitive Psychology*, 29(6), 653–669. doi:10.1080/20445911.2017.1310109.

Stoops, A., & Christianson, K. (2019). Parafoveal processing of inflectional morphology in Russian: A within-word boundary-change paradigm. *Vision Research*, 158, 1–10. doi:10.1016/j.visres.2019.01.012.

Taft, M. (2004). Morphological decomposition and the reverse base frequency effect. *The Quarterly Journal of Experimental Psychology Section A*, 57(4), 745–765. doi:10.1080/02724980343000477.

Tovar, A. T., Fein, D., & Naigles, L. R. (2015). Grammatical aspect is a strength in the language comprehension of young children with autism spectrum disorder. *Journal of Speech, Language, and Hearing Research*, 58(2), 301–310. doi:10.1044/2014_JSLHR-L-13-0257.

Velan, H., Deutsch, A., & Frost, R. (2013). The flexibility of letter-position flexibility: Evidence from eye movements in reading Hebrew. *Journal of Experimental Psychology: Human Perception and Performance*, 39(4), 1143–1152. doi:10.1037/a0031075.

Yan, M., Zhou, W., Shu, H., Yusupu, R., Miao, D., Krügel, A., & Kliegl, R. (2014). Eye movements guided by morphological structure: Evidence from the Uighur language. *Cognition*, 132(2), 181–215. doi:10.1016/j.cognition.2014.03.008.

Yen, M.-H., Tsai, J.-L., Tzeng, O. J.-L., & Hung, D. L. (2008). Eye movements and parafoveal word processing in reading Chinese. *Memory & Cognition*, 36(5), 1033–1045. doi:10.3758/MC.36.5.1033.

10

NEURAL PROCESSING OF MORPHOLOGICAL STRUCTURE IN SPEECH PRODUCTION, LISTENING, AND READING

Laura Gwilliams and Alec Marantz

Introduction

The psycholinguistic investigation of morphologically complex words typically involves manipulating features of language (e.g., stem frequency, morphosyntactic agreement, semantic transparency) and measuring associable differences in behavioral output (e.g., reaction time and accuracy in a lexical decision paradigm). Assuming that the only differences between experimental conditions are the linguistic features of interest, any reliable change in behavior can be interpreted as the extent to which those features matter for language processing. The rationale is that, by understanding what experimental manipulations make language processing more or less "effortful," it is possible to answer central cognitive questions such as "what linguistic content is stored in memory?" and "how is it accessed?"

Some researchers, the neurolinguists, use brain measurements instead of behavioral measurements to address these questions. The experimental rationale is shared across approaches, except speed of reaction time is commonly replaced with strength of neural activity at a particular spatial location in the brain at a particular moment in time. The goals of neurolinguistic research are not only shared with, but critically build upon, psycholinguistic approaches. Within the domain of morphological processing specifically, the shared cognitive questions concern what representations are stored and how they are accessed and combined. The additional neural questions are, of course, brain-specific: put simply, *where* and *when* in the brain do these processes happen? The point of answering the brain-specific questions is to be able to understand how information passes through the cortex and what computations are applied at different processing stages. In this chapter, we review selected evidence from studies that use neural recordings to understand the role of morphology in speech production, reading, and speech comprehension. We focus on exemplary research that is solidly grounded in linguistic theory and

DOI: 10.4324/9781003159759-10

that tests the cognitive relevance of putative language features and processing stages with neural data.[1]

Before diving into the literature, let us address the pressing question: given the wealth of insight that can be gained using behavioral measures, why invest additional money and time into taking neural measures of language processing? When the brain is presented with a linguistic stimulus, such as a written word on the screen, neural activity starts at a particular location (e.g., visual cortex) and then spreads to different areas of the brain, culminating in word recognition and/or a button-press response. This happens quickly, within about half a second for a word presented in isolation. Using neuroimaging techniques, it is possible to measure the consequences of language feature manipulations on neural activity as it propagates through the brain and, from this, to infer the neural computations that happen during activity flow. Popular non-invasive imaging techniques for addressing these questions include electroencephalography (EEG), magnetoencephalography (MEG) (these are best for understanding *when* neural processes occur), and functional magnetic resonance imaging (fMRI) (this is best for understanding *where* in the brain these processes occur). Invasive human neural recordings include electrocorticography (ECoG) and stereo-EEG (s-EEG), which provide excellent temporal and spatial resolution, though the brain areas being recorded from are determined by clinical needs.

Neural measurements allow certain limitations of behavioral measures to be overcome. First, the response of a subject in any given trial is the consequence of multiple, complex, and interacting processes in the brain. These include not just language related processes, but also processes related to the sensory input (e.g., general visual or auditory processing) and motor output (e.g., fine finger movements to conduct a button press). The resulting behavior is the summation of all of these processes together, which can work in opposing directions with respect to button-press reaction times to potentially wash out measurable effects of language structure. This means that a language feature that influences neural processing may not necessarily be detectable from behavioral measurements. Second, by having access just to the “end product” of these processes and not the intermediate steps, it becomes difficult to make precise inferences about what stages of processing (e.g., early segmentation versus later combination) a feature is involved in. This places limits on the specificity with which researchers can understand the architecture the brain uses to process language.

Using neuroimaging and neurophysiological recordings, researchers have made significant progress in understanding the pipeline of processes that uphold morphological processing in the brain, both when producing and when comprehending language using writing and speech.

On the production side for morphologically complex words, the operations comprise at least a “look-up stage” and a “combination stage” of the grammatical morphemes, where the morphemes are independent of their articulatory and phonetic realizations. This is followed by the activation and sequencing of the motor representations of the articulatory realization of the morphemes. The working assumption of a linguistically sophisticated account of word production, shared with production theories in Levelt (1989)'s and Levelt et al. (1999)'s accounts, is that an a-modal morpheme or "lemma" level of processing feeds the "lexeme" level of phonological—here articulatory phonological—representations.

On the comprehension side, the sequence of operations minimally comprises "decomposition" into the phonological or orthographic forms of morphological constituents, "look-up" of the stored representations of the syntactic and semantic constituents in memory, and "composition" of the representations into full lexical items. Because a complete summary of this work is out of the scope of the current chapter, we focus on segmentation into "lexemes" or the orthographic and phonological forms of morphemes, discussing a set of research topics we consider central to understanding morphological processing in the brain.

The research we review here is also solidly grounded in linguistic theory, particularly that of Generative Grammar and Distributed Morphology (Halle & Marantz, 1993). Theory can be used to generate hypotheses both in terms of what units of language matter, what features make up those units, and what processes allow them to be accessed and combined. Before going into the neurolinguistic results, we first want to be explicit regarding the status of the morpheme in current linguistic theory.

The Role of the Morpheme in Current Linguistic Theory

Within neurolinguistics, research on lexical processing and morphology has been heavily influenced by Levelt's (1989) theory of language production. For stems at least, Levelt postulates an abstract "lemma" node between the stem's meaning representation and its phonological form, called a "lexeme." The separation of the lemma from the lexeme allowed for the possibilities of multiple lexemes for the same lemma for different modalities; for example, there might be a "phonological input" lexeme stored in auditory perception areas of the brain and a separate, but presumably connected, "orthographic input lexeme" stored along the ventral visual-object-processing stream in areas associated with the recognition of visual objects including words and faces. Work from Caramazza's group on dissociations of language deficits across different modalities (e.g., problems in auditory word comprehension but not in reading, and vice versa) led Caramazza (1997) to delineate these different "lexica" (storage areas for lexemes) and argue for a distributed neural lexicon. Observations about double dissociations in deficits between syntactic categories (e.g., deficits for nouns but not verbs, and vice versa) led Caramazza (1997) to further argue that "lemma" representations were not featureless hubs in the lexical network but rather consisted of bundles of syntactic features, including syntactic category features. Caramazza's model, then, comes to resemble strongly the representations of Distributed Morphology, with the syntactic "morpheme" of the latter corresponding to the lemma of the former (and to the Levelt model).[2]

The research we will describe below is informed by and supports the consensus view of morphology from linguistic theory, aphasia, and computational learning research: the "morpheme" (or lemma or lexeme [Baayen et al., 2016]) is an abstract syntactic object (from sound and meaning) that mediates between meaning and form representations. In addition, the research relies on an assumption that joins the "connectionist" learning literature with the theoretical linguistics literature in opposition to a "dualist" tradition made famous by Pinker's work on the English past tense (e.g., Pinker, 1991). On the dualist (or "dual-route") approach, one might recognize a morphologically complex word by retrieving a whole-word representation from memory or by computing a complex-word representation using one's grammar. Within linguistic theory, the grammar of a language "stores" all the words (and sentences) of the language. Retrieving a morphologically complex word from memory and computing the word with one's grammar are essentially the same process: the grammar is one's memory store. This conception of the grammar mirrors the connectionist approach to morphology, where storage and grammar are two ways of looking at the same network, although of course there are differences in the implementation of this insight (see Marantz, 2013 for a review of the issues).[3]

Production: Inflectional Morphology

The theory of English inflectional morphology introduced in Chomsky (1957) makes a sharp distinction between the syntactic derivation of an inflected main verb, which involves "hopping" a tense morpheme onto a verb stem within a phrase structure tree, and the phonological realization of the tense morpheme, which involves the subsequent insertion of a phonological form into the tense morpheme. Within contemporary Generative Grammar, this sharp distinction is maintained, with the syntactic component of the grammar manipulating a tense morpheme (fronting it, for example, in matrix questions) and the morphophonological component inserting a phonological form (a "Vocabulary Item" or morph) into the morpheme node during the phonological realization of the syntactic structure. Sahin et al. (2009) draw predictions from such a model for an experiment in which they measure neural responses from pre-operative patients that have depth electrodes situated in their pre-frontal cortex. Specifically, in a task involving the (silent) production of a past or present form of a verb from a visual presentation of its stem, Sahin et al. (2009) predict a neural response associated with syntactically attaching the tense morpheme to the stem, regardless of its eventual pronunciation, followed by a neural response associated with the sequencing of the phonological form of the stem with that of the tense suffix, if the tense suffix is non-zero (i.e., if it has an overt phonological form). Although irregular morphology (as in the English irregular past tense forms) involves processing considerations that rely on specific stem knowledge (which stems take marked forms in the past, and which trigger marked endings), the general predictions for these two stages of tensed verb formation are the same for irregulars and regulars: syntactic affixation followed by the phonological concatenation of non-zero phonological forms.

In addition to the regular and irregular past tenses of verbs, Sahin et al. (2009) employed regular and irregular noun plurals, to test whether their results for inflection generalize across syntactic categories. They presented subjects visually with a cue phrase followed by the target word in an uninflected form. Responses were measured in epochs starting at the presentation of the target word. The experiment included both verbs and nouns. For verbs, the zero present tense inflection was required for the frame "Every day they." For nouns, the zero singular number inflection was elicited with the frame "That is the." The overt inflections were triggered by "Yesterday, they" and "Those are the" for verbs and nouns, respectively. The non-inflected "read" condition was elicited with the frame "Repeat word."

In the responses over electrodes, a response peak around 200 ms post target presentation was modulated by the stem frequency of the target word. Sahin et al. (2009) propose that this response indexes lexical access of the stem—the response latency for a response component in inferior frontal areas associated with word frequency is consistent with results from MEG experiments on reading. At around 320 ms post target, a response showed a contrast between both the overt and covert inflection conditions, on the one hand, and the repeat/read condition, on the other, with a greater response amplitude for the inflected conditions, whether overt or covert. This component is interpreted as indexing the stage of grammatical processing, adding the morpheme to the stem. Finally, at around 450 ms there is a peak response that shows a greater amplitude for the overt inflection conditions as opposed to the covert inflection and repeat/read conditions. This component is interpreted as indexing the phonological processing of the stem plus overt suffix combination.

There is much to say to about this experiment, both on its merits and its limitations. For example, although the responses correlated with the proposed stages of inflected word production come from inferior temporal sites, the experiment doesn't demonstrate that these sites are the only brain areas involved in inflection, nor does it show that they are doing the heavy lifting for the processing. The inferior temporal location was where they had s-EEG electrodes for the three patients that served as subjects. And the experiment provides additional details about the responses that are worth exploring. For example, the authors found no differences between nouns and verbs in the responses in this task, but they did find an effect of the number of syllables in the response at their 450 ms phonological component.

On the issue of the specific role of the inferior temporal cortex in inflection, Lee et al. (2018) followed up on Sahin et al. (2009) by using a patient population whose pre-surgically applied electrodes could be exploited in a disruption paradigm. Current at the parietal/temporal junction interfered with inflection in production, whether overt or covert. In an MEG follow-up to Sahin et al. (2009), Hauptman et al. (2021) replicated the result that a set of neural responses grouped inflectional processing, whether tense in verbs or number on nouns, whether overt or covert, against a word reading/repetition condition. This study implicated temporal as well as inferior frontal areas in the production of inflection, and also uncovered an effect of syntactic category independent of the inflection-processing effect.

Taken together, these three studies on the production of inflected forms in speech fully support the separation of affixes into (abstract) morphemes, on the one hand, and the forms of morphemes (the lexemes, morphs, or Vocabulary Items), on the other. In finding effects of morpheme composition across regularly and irregularly inflected verbs and nouns, they additionally question "dual-route" theories that sharply distinguish storage from computation, where these theories contrast whole-word storage for irregulars vs. composition for regulars.

Reading: Segmentation into Morphemes

As highlighted in other chapters in this volume, the majority of experimental research into morphological processing in the brain (and language processing in general) has been in the visual modality—that is, reading. Working with visual responses is analytically convenient because the entire word can be presented on the screen to the subject instantaneously, as opposed to auditory presentation where information unfolds over time. Furthermore, in terms of neural measurements, visual-word presentation evokes a large response, which has a reliable spatiotemporal trajectory from the occipital lobe in two "streams": anteriorly toward the frontal cortex (dorsal stream) and toward the temporal pole (ventral stream). The flow of neural activity can be queried at different moments in time, at different locations in the brain, with consistent reproducibility across studies and experimental paradigms. This consistency in neural responses has allowed experimenters to identify particular peaks in the brain signal as "response components." These components are characterized by (i) the latency relative to visual-word presentation; (ii) the location of the neural signal at that given latency; and, importantly, (iii) what features of the language input seem to modulate neural activity.

One of the most relevant of these components for visual morphological processing is the N/M170 (if recorded with MEG: M = "magnetic"; if recorded with EEG: N= "negative"). This response component was first discovered for its sensitivity to faces over other visual objects. It peaks at ~170 ms after visual presentation onset and locates to the fusiform gyrus bilaterally (Eimer, 2000; Liu et al., 2000; Rossion et al., 2000). This response was later found to show sensitivity to visual-word complexity. For example, the frequency of the stem morpheme, the transition probability between stem and suffix, and how many morphemes a word contains all modulate N/M170 response amplitude (Cavalli et al., 2016; Fruchter & Marantz, 2015; Gwilliams et al., 2016; Gwilliams & Marantz, 2018; Lavric et al., 2007; Lehtonen et al., 2011; Lewis et al., 2011; Morris et al., 2008; Morris et al., 2013; Pylkkänen et al., 2004; Solomyak & Marantz, 2010; Whiting et al., 2015; Zweig and Pylkkänen, 2009). This word-complexity response is dominant in the left fusiform gyrus, overlapping with the putative "Visual Word Form Area": a region in the left lateral occipitotemporal sulcus that responds preferentially to word strings and that is invariant to the spatial location of the word as well as font and case (Cohen and Dehaene, 2004; Cohen et al., 2000).

Finding a response along the ventral visual stream that tracks the morphological complexity of the written input aligns well with psycholinguistic research suggesting that morphemes are segmented primarily based on orthographic regularity, and not on the semantic relatedness between the constituents and the whole word (McCormick et al., 2008; Rastle & Davis, 2003; Rastle et al., 2004). And overall, this response has proven so reliable that it can be used as a neural marker (or "litmus test") of whether the brain considers a written word morphologically complex or not (Gwilliams & Marantz, 2018).

Why would such a litmus test be useful—surely as language researchers we can *a priori* classify words into morphologically complex and simple, and therefore decomposable and not decomposable? It turns out that this is not so straightforward. Understanding what the brain processes via decomposed constituent morphemes is informative for our central cognitive question: if a word is processed via constituent morphemes, we can infer that those constituents are stored in memory. The kinds of words that are processed decompositionally tell us something about the cues that the brain uses (and doesn't use) to recognize that a word should be accessed through smaller constituents. Thus, testing what the brain considers morphologically complex actually provides theoretical insight into how linguistic information is stored and accessed during processing.

Let's take a couple of examples. Is a word like *taught* morphologically complex? Such an irregular form does not follow the morphological rule that governs past tense verb formation (i.e., *teach* + past tense *ed*), so perhaps irregular words are stored as whole-word forms and processed differently from regular forms such as *blinked*. Stockall and Marantz (2006) tested exactly this hypothesis, to evaluate whether all complex forms, regardless of their regularity, are processed through using the same obligatory decompositional parser, which identifies the internal structure of words in terms of their constituent morphs or Vocabulary Items, or whether, alternatively, regular complex words are processed in one way and irregular forms are processed in a different (non-decompositional) way.

Using MEG, the authors tested whether responses at the M170 distinguish between regular and irregular forms in a priming paradigm. Both regular allomorphs of a root (date-DATED) and irregular allomorphs (teach-TAUGHT) led to the same degree of priming and modulation of the M170 component as compared to an orthographic+semantic control—words related both orthographically and semantically but not morphologically (boil-BROIL).[4] This suggests that even morphologically complex words that do not follow regular morphosyntactic patterns are processed using the same set of computations as regular complex words. Specifically, even irregular forms that do not obey the typical orthographic transformation are recognized as complex by the visual system at the stage where it processes a string of letters into a set of morphs (the visual forms of morphemes). And in turn, the results indicate that irregular past-tense forms are not stored as whole-word forms in the mental lexicon, but instead are stored as morphological constituents just like their regular counterparts.

To take another example: are words like *excursion* or *detonate* morphologically complex? These items seem to contain a root (*excurse* and *deton*) and a suffix morpheme (*-ion* and *-ate*), and the suffix obeys the morphosyntactic rules of the language (the derivational rules that govern the use of *-ion* and *-ate* allow a speaker to assign a meaning to the bound stems *exurse* and *deton*, and compute the syntactic category of the whole words *excursion* and *detonate* from these bound stems, even though the stems arguably occur only in these words). From a linguistic perspective, then, the answer would be "yes, *excursion* and *denotate* are morphologically complex." However, usually, root morphemes enjoy a higher frequency than whole words because they occur in multiple lexical contexts. For example, the root *appear* occurs in multiple lexical contexts such as *appeared, appears, disappear*, and *appearance*. Because root frequency is calculated as the sum of all contexts the root occurs in, the frequency of any single context (e.g., the complex form *appeared*) is just a subset of the total uses of the root, and thus of a lower frequency by definition. Based on this frequency difference between roots and complex forms, it has been argued that there is a computational advantage to processing complex forms via morphological constituents because the constituents are more readily accessible than the whole. In "excursion"-type cases, the root morpheme (putatively "excurse," though, as we have seen, it does not appear independently in English) does not exist within any other word or in isolation. Therefore, there is no frequency advantage to processing such an "excursion"-type item compositionally.

Another way of framing the ratio between root morpheme frequency and whole-word frequency is as a *transition probability*. This means that, as the term suggests, having read (or heard) the root morpheme, what is the probability of a particular suffix attaching to that root? This is computed as the frequency of the root divided by the frequency of the root+suffix. Most morphologically complex words have a transition probability of less than 1, because multiple suffixes can attach to the root. Words like *excursion* and *detonate*, however, have a transition probability equal to 1, because after reading or hearing the root it can be known with total certainty what will come afterward.[5]

It is unclear, therefore, for words where the root frequency is equivalent to the whole-word frequency, whether the root is stored as a constituent separate from its suffix or if the whole form is stored as a single constituent. If a word with a "unique" root like *excursion* is stored via decomposition into *excurse* and *-ion*, and if M170 activity is modulated by the transition probability from stem to suffix, then we expect words like *excursion* to trigger an M170 response predicted by a transition probability of 1, rather than an M170 response correlated, say, with the frequency of the word.

Gwilliams and Marantz (2018) addressed this question of the decomposition of unique-root words by presenting subjects with uncontroversially complex words such as *sociable* and *topical*, and compared the M170 responses to these words with the M170 responses to morphosyntactically decomposable unique-root words (e.g., *excursion*) and to words analyzable as stem plus existing suffix but incompatible with the grammar of English if categorized as unique-root words (e.g., *winter*—meaning not compatible with productive use of the *-er* suffix: not plausibly one who "wints"). M170 responses were indistinguishable between the morphosyntactically valid words (*excursion*) and the complex forms (*sociable*), and both were significantly different from the morphosyntactically invalid forms like *winter*. Words like *excursion* showed M170 amplitudes predictable from a putative transition probability from stem to affix of 1 (given the correlation between transition probability and M170 amplitude computed from the *sociable* words), while words like *winter* did not. Although this is a simple result, it again has considerable consequences for our understanding of written-word processing. This finding suggests that the brain has memory representations of root morphemes, and uses them, not just when it is statistically more efficient to do so (when the stem morpheme is more frequent than the whole word), but also when the putative morphological structure of the word entails the existence of root morphemes that *should* exist but do not exist in other morphological contexts in the language. That is, the grammar demands the decomposition, with consequences for the storage of and access to the form representation of morphemes in the ventral processing stream.

Related to this line of research, there is also evidence that the visual system parses pseudo-complex words like *corner* and *brother* into constituent root and suffix morphemes (e.g., *corn, broth*, and *–er*; see Rastle et al., 2004 and related work). This is an important observation because, as the reader may have realized, *corn* is not morphologically related to *corner*; similarly, *broth* is not related to *brother*. Using MEG, Lewis et al. (2011) found that the transition probability between the pseudo-stem (*corn, broth*) and pseudo-suffix (*-er*) significantly modulates responses in the fusiform gyrus at the M170 response. This suggests that, during the early visual processing of a written word, the system is sensitive to the number of morphological constituents contained in the input, and it initiates a decompositional parse when all of the orthographic input can be explained as constituent units (as the orthographic forms of morphemes). From this perspective, "winter"-type words are not decomposed, because there is no valid root morpheme to explain the orthographic sequence *wint*. Neural responses do not, however, distinguish between truly complex words (e.g., *farmer*) and pseudo-complex words (e.g., *brother*). This suggests that the morphological processing stage identified by the M170 response from the Visual Word Form Area is insensitive to whether the composition of the morphemes realized by the identified morphs generates the complex whole when analyzed morphosyntactically.

Overall, the results of these three lines of research converge on two take-home messages. First, the brain errs on the side of constituent storage as opposed to whole-word form storage (where by "whole-word form" we mean a morph or Vocabulary Item without internal structure). This involves on-the-fly computation and assembly, even where a stem only occurs when it is followed by a particular suffix. We saw that even in cases where words are formed through irregular morphological processes (e.g., *taught*), when constituent frequency was equal to whole-word frequency (e.g., *excursion*), and when a compositional parse does not yield the whole-word form (e.g., *brother*), the brain still launches a decompositional parse. Second, the visual system employs a set of intelligent criteria to determine whether or not to initiate that parse. Again, we saw that even in the absence of an orthographic suffix string (e.g., there is no "ed" in "taught"), and even when the transition from root to suffix is certain, the brain recognizes the item as complex and continues to process it via its constituents.

Both of these results suggest that the visual system is not attempting to match orthographic forms to stored visual "templates" of roots and suffixes in a bottom-up manner, given that those templates do not exist for irregular, bound, and unique-root items. Instead, a mapping occurs from stored abstract forms (the syntactic morphemes or lemmas) to the orthographic input. In order for this mapping to be initiated, all morphological constituents of the orthographic input (e.g., *both* root and suffix lexemes or morphs) need to be accounted for, which will allow the brain to process the word decompositionally; otherwise, it is recognized and processed as a single unit.

What this body of work highlights, therefore, is that there exist reliable neural responses to written words, which can be fully characterized in terms of their sensitivity to different features of the language input. Once characterized, it is possible to associate neural responses at a particular latency in a particular region to specific neural computations. Based on how such responses behave when faced with different inputs, we can make inferences about what linguistic information is stored in memory and subsequently retrieved during visual-word recognition.

Listening: Effects of Morphological Structure

Morphological structure is of course not just relevant for reading, but also for listening; however, as mentioned above, morphological processing in speech has been much less studied. There are a few reasons why. Unlike visual processing, where the whole word is presented on the screen at the same time, a spoken word like *disappears* may unfold over the course of about a second. Considering how quickly the brain processes language input, the question becomes not only *when* does a neural process occur, but also *relative to when* in the speech signal itself. For example, when during *disappears* could you derive the frequency of the whole word, or of its constituent parts? And when could you recognize that this word is morphologically simple or complex?

One approach to addressing these questions has been to capitalize on the brain's acute sensitivity to phoneme predictability. It has been shown in previous work that neural responses in the auditory cortex—specifically, the left superior temporal gyrus (STG)—are modulated by how predictable a heard phoneme is. Less predictable phonemes elicit a stronger response than more predictable phonemes (Gagnepain et al., 2012). Ettinger et al. (2014) looked at whether this phoneme predictability response was additionally modulated by whether or not the phoneme occurred in the context of a morpheme boundary. For instance, one of the stimuli pairs contrasted the words *bourbon* and *bruiser*. In that case, the question is whether the response at the final vowel is higher when it occurs as the first phoneme in a suffix, given a baseline of the phoneme "surprisal" computed over the cohort of whole words consistent with the input processed at that vowel. The authors not only replicated previous phoneme predictability results, but also found that the predictability effect was stronger at morpheme boundaries than it was at word-internal positions in monomorphemic words. The implication of this finding is that the brain not only processes speech by predicting what phonemes it will hear next, but also by predicting what morphemes it will hear next. That being said, the study does not provide any formula for phoneme surprisal in the context of morpheme boundaries that predicts the magnitude of the surprisal response in the experiment.

Building from these results, Gwilliams and Marantz (2015) assessed whether phonological sequences are processed via morphological constituents in languages with a non-concatenative morphology, such as Arabic. This is important because in Arabic the order of phonemes in the sequence is actually not the same order as that of the morphemes in the sequence. So, a word like *kataba* ("he wrote") comprises a root morpheme {k-t-b} and an inflectional morpheme pattern {CaCaCa}, where the "C" positions are placeholders for root consonants. Thus, each phoneme of the input actually interleaves the morphological structure in an alternating manner. In this case, the question is: are predictions about upcoming phonemes based on the full sequence of preceding phonemes in the word ({k-a-t-a-b-a}: a whole-word predictive mechanism), or are they based on the preceding phonemes within the root morpheme ({k-t-b}: a root-internal predictive mechanism)? The authors collected MEG responses to spoken Arabic words, and analyzed responses to the final consonant of the words (e.g., [b] in *kataba*) as a function of (i) whole-word predictability; and (ii) root-internal predictability. Their results suggest that left STG responses at around 150 ms after phoneme onset are sensitive to the root-internal likelihood of a phoneme. Subsequent responses at around 300 ms are sensitive to whole-word likelihood, which correlates with the likelihood of the root given the inflectional frame. Therefore, this result suggests that the brain generates predictions of, and primarily and preferentially processes phonetic content relative to, the morphological structure of spoken words, with non-contextual root identification preceding computation of the probability of the root given the inflectional frame. And this is true even in cases where the morphological structure is at odds with the linear order of the phonological input itself.

In another study addressing the form of and access to morphological knowledge, Gaston and Marantz (2018) explored the processing of words like *clash* that have semantically related noun and verb uses. In a theory like Distributed Morphology (DM; Halle & Marantz, 1993), such words share a single root representation; the noun and verb uses involve distinct nominalizing and verbalizing affixes attached to this single root. In competing Lexicalist theories, such words have two independent but related lexical representations, one a noun and one a verb, but share no internal constituents. The experiment presented subjects with auditory stimuli consisting (in the cases relevant here) of a "to" (an infinitival marker I) or a "the" (a determiner D) followed by the ambiguous word. The preposition or determiner thus disambiguated the syntactic category of the following word. On the DM account, before the context provided by the I or D, the relevant "cohort" of words that would determine the probability of upcoming phonemes would be all words, nouns and verbs, that start with the sounds encountered. DM would be consistent with a stage of processing in which the stems that could only be used as verbs (if the context was I) or as nouns (if the context was D) were dropped from the cohort and phoneme surprisal was computed—before any modulation of the frequency of category-ambiguous roots like *clash* based on their relative frequency with a nominalizing or verbalizing suffix. This could be followed by a second stage in which the frequency contribution of the ambiguous roots to the cohort was modulated by the contextual frequency of the roots in the I or D context. A Lexicalist theory would not be compatible with the existence of these two stages; rather, in such a theory, when the nouns are dropped from the cohort in the D environment and the verbs in the I environment, the noun or verb uses of the ambiguous items would also be dropped, as they are separate words from their other uses. This study provided support for both the stages allowed by DM but prohibited by Lexicalist theories, giving further credence to the theory that noun/verb ambiguous words with semantically related meanings in the two uses share a single morpheme representation across the uses, a representation that actively figures in the auditory recognition of what DM analyzes as morphologically complex words (a stem plus a phonologically null categorizing suffix).

As may be apparent, progress in understanding morphological processing in speech is not as advanced as that in reading. However, the studies highlighted here do not just reveal empirical results, but also offer an analytical framework upon which to address further, more nuanced, research questions by using information-theoretic measures (e.g., surprisal, entropy) to model processing as a function of putatively active linguistic representations (Gwilliams & Davis, 2021).

Conclusion

Our results summarize a set of theoretically motivated neurolinguistic studies investigating the role of morphological structure in speaking, reading, and listening, all involving measures of electrical activity in populations of neurons in the brain. These studies support a linguistically informed account of the storage and access to sub-word units in the processing of morphologically complex words. In particular, the experiments highlight the separation between (i) how the forms of morphemes (the morphs, lexemes of Vocabulary Items) are stored and accessed within modality-specific brain regions; and (ii) the amodal abstract morphological representations to which they are connected. The content of these form representations is determined by the grammar as a whole, not exclusively by considerations of visual or auditory parsing. Thus, the operation of combining a stem morpheme with an inflectional morpheme is computationally the same regardless of whether the inflectional morpheme has any phonological content at all. It is only at the level of motor articulation and planning that phonologically overt and phonologically null suffixes differ. The letter strings *excurs-* and *ion* are distinct orthographic form representations, even though the stem only appears in the context of this suffix. And the auditory form representation of Arabic root morphemes is distinct from the representation of the inflectional frames in which they appear, even though the temporal experience of listening to Arabic words interleaves the forms of the roots and the forms of the frames. The fact that these studies largely involved linguistic variables modulating brain responses in the absence of significant modulation of the behavioral responses in the experiments speaks to the utility of neurolinguistic methods for the advancement of cognitive science. The combination of theoretical linguistics and electrophysiological brain monitoring promises to provide crucial insights that will help us answer our central cognitive questions.

Notes

1 We should note that our summary of research in this chapter is not meant to be any kind of a systematic review of the neurolinguistics of morphology. Rather, we concentrate on studies, mostly from our research group, that best illustrate the main themes of the integration of linguistic theory with cognitive neuroscience. For a recent review paper, see Leminen et al. (2019).
2 Here, we choose to gloss over differences between the models of Levelt (1989) and Caramazza (1997) in order to emphasize the commonality between their theories and between these lemma-based theories and DM.
3 In their chapter in this volume, Aronoff and Sims also point to the separation of the abstract morpheme/lemma from the concrete form/lexeme and the lack of a clear distinction between storage and computation as key points in understanding the relationship between linguistic theory and the cognitive science of language. They also discuss how "lemma" and "lexeme" find different uses across different subdisciplines, some of which do not line up with the characterization given here.
4 But see Rastle et al. (2015) for an incomplete replication of these results using EEG.
5 Note that transition probability is an interesting metric to think about for visual-word processing given, as we say above, that the entire word is presented on the screen at the same time. Thus, unlike auditory processing, there is no sensory uncertainty per se about what will come "next," because, well, there is no "next." Yet, despite this, transition probability has been shown to reliably modulate responses to visually presented words at the M170 in a number of studies (Gwilliams et al., 2016; Lewis et al., 2011).

References

Baayen, R. H., Shaoul, C., Willits, J., & Ramscar, M. (2016). Comprehension without segmentation: A proof of concept with naive discriminative learning. *Language, Cognition and Neuroscience*, 31(1), 106–128. doi:10.1080/23273798.2015.1065336.

Caramazza, A. (1997). How many levels of processing are there in lexical access? *Cognitive Neuropsychology*, 14(1), 177–208. doi:10.1080/026432997381664.

Cavalli, E., Colé, P., Badier, J. M., Zielinski, C., Chanoine, V., & Ziegler, J. C. (2016). Spatiotemporal dynamics of morphological processing in visual word recognition. *Journal of Cognitive Neuroscience*, 28(8), 1228–1242. doi:10.1162/jocn_a_00959.

Chomsky, N. (1957). *Syntactic structures*. The Hague: Mouton.

Cohen, L., & Dehaene, S. (2004). Specialization within the ventral stream: the case for the visual word form area. *Neuroimage*, 22(1), 466–476. doi:10.1016/j.neuroimage.2003.12.049.

Cohen, L., Dehaene, S., Naccache, L., Lehéricy, S., Dehaene-Lambertz, G., Hénaff, M. A., & Michel, F. (2000). The visual word form area: Spatial and temporal characterization of an initial stage of reading in normal subjects and posterior split-brain patients. *Brain*, 123(2), 291–307. doi:10.1093/brain/123.2.291.

Eimer, M. (2000). Event-related brain potentials distinguish processing stages involved in face perception and recognition. *Clinical Neurophysiology*, 111(4), 694–705. doi:10.1016/s1388-2457(99)00285-0.

Ettinger, A., Linzen, T., & Marantz, A. (2014). The role of morphology in phoneme prediction: Evidence from MEG. *Brain and Language*, 129, 14–23. doi:10.1016/j.bandl.2013.11.004.

Fruchter, J., & Marantz, A. (2015). Decomposition, lookup, and recombination: MEG evidence for the full decomposition model of complex visual word recognition. *Brain and Language*, 143, 81–96. doi:10.1016/j.bandl.2015.03.001.

Gagnepain, P., Henson, R. N., & Davis, M. H. (2012). Temporal predictive codes for spoken words in auditory cortex. *Current Biology, 22*(7), 615–621. doi:10.1016/j.cub.2012.02.015.

Gaston, P., & Marantz, A. (2018). The time course of contextual cohort effects in auditory processing of category-ambiguous words: MEG evidence for a single "clash" as noun or verb. *Language, Cognition and Neuroscience*, 33(4), 402–423. doi:10.1080/23273798.2017.1395466.

Gwilliams, L. (2020). How the brain composes morphemes into meaning. *Philosophical Transactions of the Royal Society B*, *375*(1791), 20190311.

Gwilliams, L., & Davis, M. H. (2021). Extracting language content from speech sounds: The information theoretic approach. In L. Holt, J. Peelle, A. B. Coffin, A. N. Popper, & R. R. Fay (Eds.), *Speech perception* (pp. 113–139) Cham: Springer.

Gwilliams, L., Lewis, G. A., & Marantz, A. (2016). Functional characterisation of letter-specific responses in time, space and current polarity using magnetoencephalography. *Neuroimage*, 132, 320–333. doi:10.1016/j.neuroimage.2016.02.057.

Gwilliams, L., & Marantz, A. (2015). Non-linear processing of a linear speech stream: The influence of morphological structure on the recognition of spoken Arabic words. *Brain and Language*, 147, 1–13. doi:10.1016/j.bandl.2015.04.006.

Gwilliams, L., & Marantz, A. (2018). Morphological representations are extrapolated from morpho-syntactic rules. *Neuropsychologia*, 114, 77–87. doi:10.1016/j.neuropsychologia.2018.04.015.

Halle, M., & Marantz, A. (1993). Distributed morphology and the pieces of inflection. In K. Hale, & S. J. Keyser (Eds.), *The view from building 20* (pp. 111–176). Cambridge, MA: MIT Press.

Hauptman, M., Blanco-Elorrieta, E., & Pylkkänen, L. (2021). Inflection across categories: Tracking abstract morphological processing in language production with MEG. *Cerebral Cortex*, 32(8), 1721–1736. doi:10.1093/cercor/bhab309.

Lavric, A., Clapp, A., & Rastle, K. (2007). ERP evidence of morphological analysis from orthography: A masked priming study. *Journal of Cognitive Neuroscience*, 19(5), 866–877. doi:10.1162/jocn.2007.19.5.866.

Lee, D. K., Fedorenko, E., Simon, M. V., Curry, W. T., Nahed, B. V., Cahill, D. P., & Williams, Z. M. (2018). Neural encoding and production of functional morphemes in the posterior temporal lobe. *Nature Communications*, 9(1), 1–12. doi:10.1038/s41467-018-04235-3.

Lehtonen, M., Monahan, P. J., & Poeppel, D. (2011). Evidence for early morphological decomposition: Combining masked priming with magnetoencephalography. *Journal of Cognitive Nneuroscience*, 23(11), 3366–3379. doi:10.1162/jocn_a_00035.

Leminen, A., Smolka, E., Dunabeitia, J. A., & Pliatsikas, C. (2019). Morphological processing in the brain: The good (inflection), the bad (derivation) and the ugly (compounding). *Cortex*, 116, 4–44. doi:10.1016/j.cortex.2018.08.016.

Levelt, W. J. (1989). *Speaking: From intention to articulation* (Vol. 1). Cambridge, MA: MIT Press.

Levelt, W. J. M., Roelofs, A., & Meyer, A. S. (1999). A theory of lexical access in speech production. *Behavioral and Brain Sciences*, 22(1), 1–38. doi:10.1017/S0140525X99001776.

Lewis, G., Solomyak, O., & Marantz, A. (2011). The neural basis of obligatory decomposition of suffixed words. *Brain and Language*, 118(3), 118–127. doi:10.1016/j.bandl.2011.04.004.

Liu, J., Higuchi, M., Marantz, A., & Kanwisher, N. (2000). The selectivity of the occipitotemporal M170 for faces. *Neuroreport*, 11(2), 337–341. doi:10.1097/00001756-200002070-00023.

Marantz, A. (2013). No escape from morphemes in morphological processing. *Language and Cognitive Processes*, 28(7), 905–916. doi:10.1080/01690965.2013.779385.

McCormick, S. F., Rastle, K., & Davis, M. H. (2008). Is there a "fete" in "fetish"? Effects of orthographic opacity on morpho-orthographic segmentation in visual word recognition. *Journal of Memory and Language*, 58(2), 307–326. doi:10.1016/j.jml.2007.05.006.

Morris, J., Grainger, J., & Holcomb, P. J. (2008). An electrophysiological investigation of early effects of masked morphological priming. *Language and Cognitive Processes*, 23(7–8), 1021–1056. doi:10.1080/01690960802299386.

Morris, J., Grainger, J., & Holcomb, P. J. (2013). Tracking the consequences of morpho-orthographic decomposition using ERPs. *Brain Research*, 1529, 92–104. doi:10.1016/j.brainres.2013.07.016.

Pinker, S. (1991). Rules of language. *Science*, 253(5019), 530–535. doi:10.1126/science.1857983.

Pylkkänen, L., Feintuch, S., Hopkins, E., & Marantz, A. (2004). Neural correlates of the effects of morphological family frequency and family size: An MEG study. *Cognition*, 91(3), B35–B45. doi:10.1016/j.cognition.2003.09.008.

Rastle, K., & Davis, M. H. (2003). Reading morphologically complex words. In S. Kinoshita & S. J. Lupker (Eds.), *Masked priming: The state of the art* (pp. 279–305). New York: Psychology Press.

Rastle, K., Davis, M. H., & New, B. (2004). The broth in my brother's brothel: Morpho-orthographic segmentation in visual word recognition. *Psychonomic Bulletin & Review*, 11(6), 1090–1098. doi:10.3758/bf03196742.

Rastle, K., Lavric, A., Elchlepp, H., & Crepaldi, D. (2015). Processing differences across regular and irregular inflections revealed through ERPs. *Journal of Experimental Psychology: Human Perception and Performance*, 41(3), 747–760. doi:10.1037/a0039150.

Rossion, B., Gauthier, I., Tarr, M. J., Despland, P., Bruyer, R., Linotte, S., & Crommelinck, M. (2000). The N170 occipito-temporal component is delayed and enhanced to inverted faces but not to inverted objects: An electrophysiological account of face-specific processes in the human brain. *Neuroreport*, 11(1), 69–72. https://www.ece.uvic.ca/~bctill/papers/facerec/RossionNP2000.pdf.

Sahin, N. T., Pinker, S., Cash, S. S., Schomer, D., & Halgren, E. (2009). Sequential processing of lexical, grammatical, and phonological information within Broca's area. *Science*, 326(5951), 445–449. doi:10.1126/science.1174481.

Solomyak, O., & Marantz, A. (2010). Evidence for early morphological decomposition in visual word recognition. *Journal of Cognitive Neuroscience*, 22(9), 2042–2057. doi:10.1162/jocn.2009.21296.

Stockall, L., & Marantz, A. (2006). A single route, full decomposition model of morphological complexity: MEG evidence. *The Mental Lexicon*, 1(1), 85–123. doi:10.1075/ml.1.1.07sto.

Whiting, C., Shtyrov, Y., & Marslen-Wilson, W. (2015). Real-time functional architecture of visual word recognition. *Journal of Cognitive Neuroscience*, 27(2), 246–265. doi:10.1162/jocn_a_00699.

Zweig, E., & Pylkkänen, L. (2009). A visual M170 effect of morphological complexity. *Language and Cognitive Processes*, 24(3), 412–439. doi:10.1080/01690960802180420.

11

LOCALIST LEXICAL REPRESENTATION OF POLYMORPHEMIC WORDS

The AUSTRAL Model

Marcus Taft

Back in 1975, Ken Forster and I published a paper that described what was probably the first attempt at an explicit model of polymorphemic word recognition (Taft & Forster, 1975). Based on the finding that bound stems (e.g., *vive* from *revive*) were especially hard to classify as nonwords in a lexical decision experiment, it was proposed that such stems were lexically stored and that the logical extension of this was that prefixed words in which the bound stem occurred (e.g., *revive*) must be decomposed in order for these representations to be accessed. If this were the case, decomposition should also occur for prefixed words whose stem is a real word (e.g., *replay*), given that the lexical status of the stem cannot be known prior to its being accessed.

The model that was proposed by Taft and Forster (1975) was presented as a flow diagram, which was couched within the serial search framework that was popular at the time. It was argued that localist representations exist for stem morphemes and that these are accessed via a search through the lexicon after the polymorphemic word is decomposed. Since that time, however, the notion of lexical search has fallen out of favor (though see Murray & Forster, 2004), with the notion of parallel activation of lexical information being widely embraced, most notably within the framework of Interactive-Activation or "IA" (e.g., McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982). This conceptualization can still be seen as being localist, in that words are represented in lexical memory by specified units.

I first described the way in which polymorphemic words might be recognized within an IA framework in Taft (1991: 93–118) and explored this further in Taft (1994). Since then, my theoretical approach has continued to evolve (see, e.g., Taft, 2003; Taft & Li, 2019; Taft & Nguyen-Hoan, 2010), with the common thread being the idea that polymorphemic words always undergo decomposition in order to be recognized. That is, decomposition is pre-lexical. The present chapter

DOI: 10.4324/9781003159759-11

will outline my current conceptualization as an example of a localist model, with the focus being on derivationally complex words (as opposed to inflectionally complex words: see Taft, 2004 for an account of the latter).

The alternative to the localist approach is where morphological information simply emerges from the pattern of activation that arises as a result of form correlating with meaning, with no unitary lexical representations being identifiable. This type of approach was originally couched in terms of Parallel Distributed Processing (e.g., Rueckl, 2010; Seidenberg & Gonnerman, 2000), but in more recent times is seen in amorphous learning accounts characterized by discriminative learning models as either "naïve" (e.g., Baayen et al., 2011) or "linear" (e.g., Baayen et al., 2019). Here, statistical learning principles are applied to polymorphemic words such that the correlation between combinations of letters and the meaning of the word is captured. Adoption of this approach essentially means that the study of polymorphemic words no longer has anything to do with an interest in the linguistic structure of words, but rather with the idea that there are learning algorithms that can be applied to any type of stimulus that humans interact with. Words become anonymous objects with no individual identities.

In fact, the position that I adopt can be considered to be both localist and distributed (referred to in Taft, 2006, as "localist-cum-distributed"). The representation of orthographic form builds on units that are smaller than the whole word (i.e., letters and combinations of letters), while the representation of meaning is conceptualized in terms of semantic features. Thus, both lower-level form and higher-level meaning have distributed representations inasmuch as a number of different units contribute to the activation of other units. However, the sub-lexical form units can also be seen as being localist in nature in the sense that their individual identities are specified.

Importantly, the model includes a level of representation that mediates between form and function, and the units at this level (referred to as "lemmas") are conceptualized entirely in localist terms. The fact that these units represent specific entities helps to provide a structured understanding of the processes involved in visual word recognition. Even if these mediating units are in reality distributed or can be statistically described, I believe it is more informative to refer to them in localist terms in order to envisage how the system works. After all, a model is meant to provide as concrete a way as possible to help understand the cognitive mechanisms underlying behavior so that it can explain that behavior and stimulate predictions. The mere reproduction of human behavior through the application of computational processes is not very informative when the question being asked is how we read polymorphemic words. It adds nothing to our understanding, if all we can say is that we read polymorphemic words by setting up certain patterns of activation in the brain on the basis of the letters that we are presented with. A localist account allows us to trace through the steps involved in recognizing particular types of words, and make predictions about the relative difficulty in recognizing them based on their characteristics or their manner of presentation.

The AUSTRAL Model

The localist (cum-distributed) model that I have been advocating will be referred to as AUSTRAL, which is an acronym of Activation Using Structurally Tiered Representations and Lemmas. The "structurally tiered representations" are found within the level where orthographic form is realized. The largest grain-size of such form units are syllables that are orthographically defined (see below), and below these are sub-syllabic units such as letters, graphemes, onsets, codas, and bodies (see Taft et al., 2017). As illustrated in Figure 11.1 using the example of *cashew*, activation passes through units corresponding to the individual letters (arbitrarily depicted in uppercase) and ultimately the form units CASH and EW are activated. The intermediate orthographic units (e.g., the grapheme/coda SH and the body ASH) are not directly relevant to the issue of polymorphemic word recognition, but are included for the sake of completeness and to emphasize how, despite the word form being distributed across a number of smaller units, identification of what these units are is potentially informative.

The central feature of the model is the existence of a lemma level that contains abstract units that mediate between the form representations and the higher-level functional units that provide the meaning, part of speech, and any other information relevant to the word. The lemma units can be seen as the lexical representations,

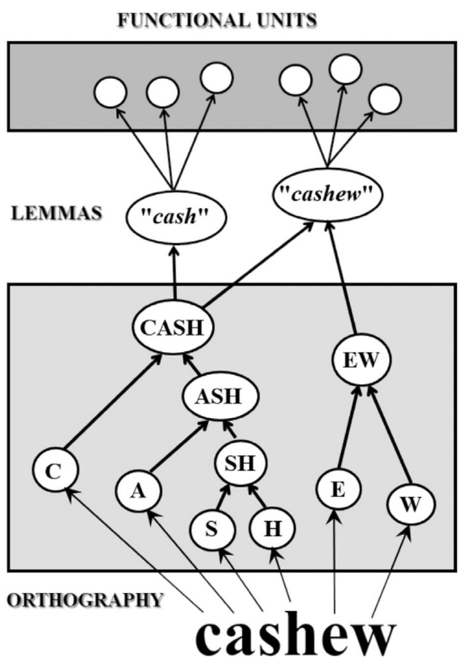

FIGURE 11.1. Interactive-Activation model incorporating lemma units (the AUSTRAL model) using the monomorphemic word *cashew* to illustrate.

which means that a lexical decision response (deciding whether a presented letter-string is a real word or not) is determined on the basis of the existence of a relevant lemma unit. Although lemmas do not necessarily correspond to freestanding words (see below), it is still possible to explain how lexical decision responses can be made on the grounds that a lemma exists—for example, on the basis of functional information associated with that lemma (see Taft, 2015) or on the strength of that lemma's representation (see Taft, 2003).

As can be seen in Figure 11.1, the lemma for the embedded word *cash* is activated along with the lemma for *cashew* when the latter is presented. However, the assumption is made that the extra activation received from the other letters (i.e., *ew*) allows the full word to successfully compete against the embedded word. Consistent with this is the fact that, as has been widely shown (see the meta-analysis of Rastle & Davis, 2008), lexical decisions to a target word are not facilitated by the prior masked presentation of another word in which it is embedded when the extra letters do not form an affix (i.e., *cashew* does not prime *CASH*). The situation is different, though, when the extra letters do form an affix (e.g., Rastle & Davis, 2008). Here, masked priming is seen both when the embedded word is transparently related in meaning to the longer word (e.g., *hunter* primes *HUNT*) and when it is not (e.g., *corner* primes *CORN*), even if the former tends to be stronger than the latter (e.g., Feldman et al., 2009; Taft & Nguyen-Hoan, 2010). How does the AUSTRAL model incorporate morphological processing, and hence explain these masked priming results?

The difference between the letter-combination *ew* in *cashew* and *er* in *corner* and *hunter* is that the latter letter-combination exists as a unit at the lemma level because it is associated with a function (e.g., an agentive function). It is then argued (e.g., Taft, 2003; Taft & Nguyen-Hoan, 2010) that there is actually a hierarchy of lemmas whereby the lemma for a transparently derived word such as *hunter* is activated via the lemmas for its stem and affix, as seen in Figure 11.2. This figure also shows that, in contrast, the lemma for a pseudo-affixed word like *corner* will be directly activated from its form units (in the same way that the lemma for *cashew* is activated), which means that the lemma for *corner* will be in competition with the lemma for *corn* just as *cashew* is in competition with *cash*. However, in contrast to the lack of *cashew-CASH* priming, *corner-CORN* priming can be found because the activation in the lemma for *er* suggests that activation in the lemma for *corn* is worth maintaining since it might turn out to be the stem of *corner* (see Taft & Nguyen-Hoan, 2010).

Whether the magnitude of such priming is the same as for transparently related words (e.g., *hunter-HUNT*) will depend entirely on how long the pre-activation of the lemma for the pseudo-stem is maintained. Since this will vary depending on the particular circumstances, it means that even a pre-lexical decomposition account (also referred to as "morpho-orthographic" decomposition) can handle variation in priming strength as a function of the transparency of the prime. That is, greater priming from transparently derived than pseudo-derived words does not necessitate the involvement of post-lexical, semantically based decomposition (i.e.,

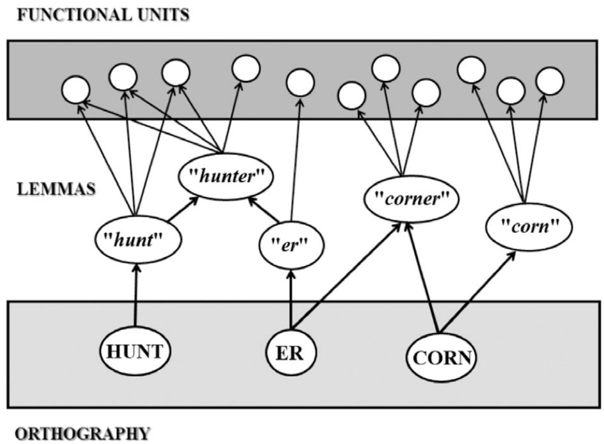

FIGURE 11.2 How AUSTRAL represents transparently derived and pseudo-affixed words, using *hunter* and *corner* as respective examples. Only the highest-level orthographic units are depicted. The functional units associated with *hunt* are activated when *hunter* is presented, while there are potential functional units associated with *hunter* that are not associated with *hunt*. The functional units associated with *corner* are completely separate from those associated with *corn*.

"morphosemantic" decomposition), as some have argued (e.g., Feldman et al., 2009). Moreover, because situations might occur where pre-activation of the lemma for a pseudo-stem (e.g., the *corn* of *corner*) is not maintained for any longer than for any other embedded word (e.g., the *cash* of *cashew*), it would even be possible to find equivalent priming for pseudo-affixed and non-affixed words (e.g., Milin et al., 2017). It also follows that, when the meaning of a pseudo-affixed word is the focus of the task (e.g., in semantic categorization or sentence processing), the resultant emphasis placed on the functional information associated with its pseudo-stem could well have an inhibitory impact on processing, owing to its conflict with the meaning of the whole word (see, e.g., Amenta et al., 2015; Hasenäcker et al., 2020; Marelli et al., 2013). So, we see that the AUSTRAL approach is flexible when it comes to the impact of pseudo-affixation on word recognition, and it does so without having to assume that semantically based decomposition occurs in conjunction with orthographically based decomposition.

The Basis for Decomposition

According to AUSTRAL, the decomposition of a polymorphemic word arises from the activation of the representations of its component morphemes. Affixes are not explicitly "stripped" as was proposed within the search framework (e.g., Taft & Forster, 1975). Polymorphemic words are treated in the same way as mono-morphemic (polysyllabic) words in terms of the way orthographic units are activated, but they differ in terms of what happens at the lemma level. As such, the activation that takes place is entirely compatible with the notion of edge-aligned embedded-word processing proposed by Grainger and Beyersmann (2017) where decomposition is said to arise on the basis of the polymorphemic word activating the word embedded at its beginning or end (e.g., the *hunt* of *hunter*, or the *write* of *rewrite*) and then establishing that this is the stem of the presented word. Because activation of the embedded word occurs pre-lexically, it must happen for any embedded word, even when the longer word is monomorphemic (e.g., the *cash* of *cashew*, the *rent* of *parent*, the *corn* of *corner*, the *cent* of *decent*). However, in such cases, the activation of the embedded word is inhibited by the activation of the longer monomorphemic word, unless the extra letters suggest that it might be polymorphemic (as with the *corn* of *corner* or the *cent* of *decent*).

Support for the idea of embedded-word activation comes from research where the masked primes are nonwords, which, having no lexical representation, will not compete with the embedded word (e.g., Beyersmann et al., 2016; Taft et al., 2018). Here, recognition of the word embedded in the nonword is facilitated regardless of whether the other letters form an affix (e.g., *huntal-HUNT, refair-FAIR*) or not (e.g., *cashop-CASH, ibrent-RENT*). The target will be activated through edge-aligned processing when the prime is presented, and, because there is no competition from a whole-word representation for the prime, recognition of the pre-activated target is facilitated. So, the fact that *cash* is pre-activated when *cashop* is presented implies that embedded words are activated regardless of the other letters in the prime and that, therefore, *cash* should also be pre-activated when *cashew* is presented. The fact that *cashew* activates a representation of the whole word in competition with that of *cash* is what prevents the recognition of the latter from being facilitated.

Note that, while the nonword *ibrent* might prime the target *RENT*, it should not prime the target *PARENT*, whose recognition pathway does not involve the word *rent*. In contrast, the nonword *idlock* should prime the target *UNLOCK*, whose recognition pathway does involve the word embedded in the prime (i.e., *lock*). In fact, Taft and Li (2020) have recently reported this pattern of results in a study that compared native and non-native English speakers, an outcome that is compatible with edge-aligned embedded-word processing and, hence, with AUSTRAL.

While the activation of the stem is central to the decomposition process in AUSTRAL, the edge-aligned activation of the remaining letters also plays a role—that is, when *hunter, corner*, and *cashew* are to be recognized, there is activation in the orthographic form unit for *hunt, corn*, and *cash*, respectively, but also in the orthographic form unit for *er* in the case of *hunter* and *corner*, and *ew* in the case of *cashew*. Unlike the unit for *ew*, the unit for *er* is associated with its own lemma, whose activation provides the basis for analyzing the word into a stem and affix (even if this turns out to be inappropriate, as in the case of *corner*). Grainger and Beyersmann (2017) emphasize the edge-aligned activation of the embedded word to differentiate their account from an affix-stripping model, but given that AUS-TRAL does not incorporate pre-lexical affix stripping, it makes sense to assume that affix representations are also activated on the basis of the edge-aligned activation of a stored representation, just as stems are. Indeed, Beyersmann and Grainger (this volume) have modified their edge-aligned processing account to include activation via both embedded words and affixes.

The Orthographic Syllable

The highest level of form unit in AUSTRAL is seen as an orthographically defined syllable. The reason for specifying that it is orthographically defined is that the alternative phonologically defined syllable often fails to capture morphological structure. For example, the spoken syllabic structure of *hunter* is *hun* + *ter*, which cuts across the morphemes *hunt* and *er*. Many years ago (Taft, 1979), I proposed the existence of an orthographic syllable that optimizes the informativeness of the main constituent of the word by maximizing the coda of that constituent (i.e., the number of consonants following the vowel). This was referred to as the Basic Orthographic Syllabic Structure (BOSS), which focused on the first constituent of the word excluding any prefixes. So, the BOSS of *hunter* is *hunt*, the BOSS of *sermon* is *serm*, and the BOSS of *inhabit* is *hab*. Although evidence has been provided for the existence of the BOSS (e.g., Chateau & Jared, 2003; Chen & Vaid, 2007; Taft, 1979, 1987, 2001; Taft & Krebs-Lazendic, 2013), it is by no means an established concept (see, e.g., Lima & Pollatsek, 1983; Perry, 2013). However, by having sub-lexical units activated on the basis of their overlap with the presented letter-string, a word can actually be recognized no matter how the reader represents its internal orthographic structure, even if use of the BOSS might be optimal (Taft, 2001). For example, regardless of whether a person activates the lemma for *sermon* through the form units *SERM* and *ON* or *SER* and *MON*, those units will be activated on the basis of the fact that they are contained within the letter-string, though advanced readers do appear to adopt the former structure (e.g., Taft & Krebs-Lazendic, 2013).

The importance of the orthographic syllable in AUSTRAL leads to an interesting prediction. The lack of *ibrent-PARENT* priming in contrast to *idlock-UNLOCK* priming (Taft & Li, 2020) is compatible with AUSTRAL because the recognition of the non-prefixed target is unlikely to engage orthographic units that correspond to the word embedded in the prime (e.g., the lemma for *parent* is more likely to be activated through PAR and ENT than PA and RENT). However, the situation is potentially different when the embedded word is at the beginning of the prime. For example, while we know that the nonword *cashop* will prime responses to the target *CASH*, it follows from AUSTRAL that *cashop* should prime responses to *CASHEW* as well. The reasoning is that the lemma for *cashew* will be activated through the orthographic syllables CASH and EW (see Figure 11.1), and therefore if the nonword prime begins with letters that correspond to CASH, this should pre-activate the lemma for *cashew* as well as for *cash*. While it might be argued that the competition between these two pre-activated lemmas will eliminate priming if either of them is then presented as the target, what can be assumed is that, because neither of them will win the competition (unlike when the prime is *cashew* itself), both will still be active when the target arrives.

So, AUSTRAL predicts that *cashop-CASHEW* priming should be observed in contrast to the lack of *ibrent-PARENT* priming. Without the idea of non-prefixed words being activated through their orthographic syllables, the Grainger and Beyersmann (2017) model makes exactly the same prediction for items like *cashop-CASHEW* as it makes for *ibrent-PARENT*, namely, that no priming should be found (in contrast to items like *sailep-SAILOR* where the target is recognized through the word embedded in the prime, namely, its stem). While such an experiment has not been reported in the literature, recent data from my lab indicates that priming is indeed significant for non-suffixed targets (e.g., *cashop-CASHEW*) in addition to suffixed targets (e.g., *sailep-SAILOR*). So, if it is true that *cashop* does prime *CASHEW* (as well as *CASH*), it provides strong support for the idea built into AUSTRAL that monomorphemic words are activated through units that correspond to orthographic syllables, where the first syllable (e.g., the BOSS) is particularly informative.

Bound Stems

As concluded from the Taft and Forster (1975) study, words with bound stems (e.g., *revive*) are recognized through a representation of that stem. The way in which AUSTRAL incorporates bound stems is to include them as form units that are associated with their own lemma in the same way that bound affixes are represented (Taft, 1994, 2003). If so, masked priming effects should be observed when the prime and target share a bound stem, even when the prime is a real word (e.g., *survive-REVIVE*), and such a result has been reported (Forster & Azuma, 2000; Pastizzo & Feldman, 2004).

A study by Taft and Kougious (2004) goes even further, and ties the idea of bound stems with the notion of the BOSS. In particular, words that share their BOSS can often be related in meaning, even when those words are not considered polymorphemic. For example, *virus* and *donate* are not typically identified as being composed of more than one morpheme, yet *virus* is clearly related to *viral* and *donate* to *donor*. On finding a masked priming effect between related pairs of this sort, Taft and Kougious (2004) concluded in favor of the AUSTRAL model (even if not referred to by this name) where, for example, the orthographic unit VIR corresponds to a lemma that sends activation to the lemmas for both the prime and the target (i.e., *virus* and *viral*). These whole-word lemmas are also activated through the form unit for the remaining letters, either mediated through a lemma (as in the case of the adjectival suffix AL) or not (as in the case of the non-functional ending US). In contrast, Taft and Kougious (2004) found no masked priming for pairs like *futile-FUTURE* where the words were unrelated in meaning but the BOSS was shared. Here, it was concluded that the lemma for the prime competes with the lemma for the target in the same way that *cashew* and *cash* are depicted in Figure 11.1, since both are activated through the same orthographic unit (FUT). Hence, any advantage that might accrue from pre-activating a shared orthographic unit is counteracted.

Graded Links between Lemmas

Figure 11.2 depicts a qualitative difference between the way in which the lemmas for a transparently affixed word (e.g., *hunter*) and for a pseudo-affixed word (e.g., *corner*) are activated. That is, the former is activated indirectly through the lemmas for its constituent morphemes, while the latter is activated directly from its form units. However, such an all-or-none difference needs to be understood in the light of results reported by Xu and Taft (2015), where the effect of base frequency on lexical decision responses was examined. "Base frequency" refers to the cumulative frequency of all words that share a stem, and, according to AUSTRAL, its effect arises from the influence of frequency on the activation of the lemma for the stem, which leads to the activation of the lemma for the whole word. Since the lemma for the stem will be activated whenever a morphologically related word is presented, it will be base frequency that determines its activation level. This explains why transparently affixed words with a higher base frequency (e.g., *grower*) are recognized more quickly than those with a lower base frequency (e.g., *surfer*) when the frequency of the affixed word itself (i.e., its "surface frequency") is controlled.

In contrast to transparently derived words, Xu and Taft (2015) found no base frequency effect for pseudo-affixed words, which is consistent with AUSTRAL because such words are not recognized via the lemma for their putative stem. However, where an issue arises is in relation to words that are partially transparent (e.g., *archer*, which refers to someone doing something with an arch-shaped piece of equipment), because lexical decision times to these words showed a base frequency effect of intermediate magnitude. Such a graded effect of base frequency can be seen as incompatible with the idea that a link between the lemma for the whole word and the lemma for the word embedded in it either exists or does not exist.

Instead, then, Xu and Taft (2015) proposed that there are always links between the two levels of lemmas, but that these are differentially weighted in a continuous fashion. The weighting is strongly positive when the relationship between the complex word and its stem is highly transparent, less positive when the relationship is weaker, and completely absent (if not negative) when the two are entirely unrelated, hence placing them in competition with each other. Thus, the all-or-none conceptualization depicted in Figure 11.2 should be seen as a way of emphasizing the difference between transparently derived and pseudo-derived words, even if that difference might be better interpreted in terms of graded weightings between inter-lemma links.

Other Localist Models

Of course, other localist models have been proposed in the literature, with some simply being variants on the AUSTRAL framework extended to languages other than English (e.g., Tsang & Chen, 2013, in relation to Chinese; Smolka et al., 2014, in relation to German). The model proposed by Crepaldi et al. (2010) is like AUSTRAL in that it incorporates obligatory pre-lexical decomposition and a lemma level. However, the lemma level is different in that it only corresponds to real words and, in keeping with most other localist models, differs from AUSTRAL by assuming that lexical decisions are based on whole-word representations in the orthographic input system. The model of Crepaldi et al. (2010) also differs from AUSTRAL inasmuch as transparently derived and pseudo-derived words are treated in exactly the same way as each other up until the level of meaning, a feature that is premised on the assumption that *corner-CORN* priming is as strong as *hunter-HUNT* priming which, as mentioned above, is not always the case (e.g., Feldman et al., 2009; Taft & Nguyen-Hoan, 2010). In addition, the Crepaldi et al. (2010) account predicts the same-sized base frequency effect regardless of derivational transparency, which is not what Xu and Taft (2015) observed.

Other localist models differ from AUSTRAL, in that they include whole-word form representations that can be accessed both directly and via pre-lexical decomposition. In some of these dual-pathway accounts, the pathway that successfully activates the word is determined by characteristics such as its frequency, length, and type of affix (e.g., Baayen et al., 1997; Bertram et al., 2000; Schreuder & Baayen, 1995). More recent versions incorporate the idea that decomposition is not only pre-lexical, but also occurs after whole-word access (i.e., post- or supra-lexically) when the word is transparently composed of morphemes (e.g., Diependaele et al., 2013; Grainger & Beyersmann, 2017; Grainger & Ziegler, 2011; Morris et al., 2013). By definition, the latter pathway is not involved in actually recognizing the word, and can only play a role in determining its meaning.

The critical difference between the dual-pathway models and AUSTRAL is the fact that the former incorporate an orthographic representation for the whole complex word that can be activated directly from the presented letter-string. In AUSTRAL, the only representation of the whole complex word is at the lemma level, with the largest form-level unit being the orthographic syllable. The whole-word lemma for a monomorphemic complex word (e.g., *corner, cashew*) is activated directly from those form-level units, while the whole-word lemma for a polymorphemic word is activated indirectly through the lemmas for its component morphemes (see Figures 11.1 and 11.2). This, however, does not preclude the possibility of a dual-pathway mechanism within the AUSTRAL framework, something that I have previously acknowledged (Taft, 2003).

According to such a modification to AUSTRAL, there would still be decomposition for all words at the form level into their orthographic syllabic structure, but the form units for a polymorphemic word would be able to not only access the whole-word lemma via the relevant morpheme lemmas, but also use direct links just like a monomorphemic word. The pathway that succeeds in activating the whole-word lemma first would depend on the relative advantage of mediating access through the morpheme lemmas, and this is likely to be a function of frequency. Given that the frequency measure that determines the ease of stem activation (i.e., base frequency) includes the frequency of its derived forms, the stem of a polymorphemic word will have a frequency that, by definition, is equal to or, in the vast majority of cases, greater than the frequency of the whole word. Thus, access to the whole-word lemma will benefit from mediation through its more readily activated morpheme lemmas, which means that the morpheme-mediated pathway will provide the basis for recognizing most transparently derived words.

Note that such a dual-pathway mechanism is quite different from that postulated in the typical dual-pathway models, because it is not a matter of whole-word access being pitted against pre-lexical decomposition, but rather one of direct access from sub-lexical form units being pitted against activation mediated through other lemmas that are accessed from those sub-lexical form units. That is, AUSTRAL always involves the decomposition of complex words into sub-lexical units (potentially via edge-aligned processing), regardless of whether those units then activate the whole-word lemma directly or indirectly. The activation of the whole-word lemma for a monomorphemic complex word is always directly achieved from the sub-lexical orthographic units, while the activation of the whole-word lemma for a polymorphemic word is usually indirectly achieved via the lemmas for its constituents, but is sometimes more efficiently achieved through the direct pathway (notably when it is of high frequency relative to its stem, e.g., *normal*, which is far more frequent than its stem, *norm*). In this way, flexibility can be built into the model.

Transposed Letter Effects

While it appears that AUSTRAL can accommodate most empirical data in relation to polymorphemic word recognition, especially with the added flexibility of having two pathways to the whole-word lemma, the model is specific enough to be falsifiable. There is one study in particular that reports data that, if shown to be reliable, presents an insurmountable challenge to AUSTRAL. This is the study of Diependaele et al. (2013). With AUSTRAL representing complex words in the same way at the form level regardless of whether they are genuinely derived or not, any disruption to the orthographic processing of a letter-string must have the same impact on all types of complex words. Against this, however, Diependaele et al. (2013) reported that *hunter-HUNT* masked priming was maintained when the stem and affix were disrupted through letter transposition (i.e., *hunetr* facilitated recognition of *HUNT* relative to a control prime), whereas *corner-CORN* masked priming disappeared (i.e., *corenr* did not prime *CORN*). Such a result is incompatible with AUSTRAL because, if the lemma for a transparently derived word can be accessed despite disruption to the activation of its form units, the same should be true for the lemma of a pseudo-derived word. In contrast, the result is explained by Diependaele et al. (2013) in terms of a their dual-pathway model by arguing that pre-lexical decomposition cannot occur when the morphemes are disrupted through letter transposition while whole-word access can still succeed. Since decomposition through the successful whole-word pathway is post-lexical and semantically determined, only the stem of a transparently derived prime will be pre-activated when its letters are transposed.

Before rejecting AUSTRAL on the basis of these data, however, an anomaly should be noted. While the pseudo-derived words of the Diependaele et al. (2013) study showed priming relative to the control condition only when the letters were intact (e.g., *corner-CORN* showed priming while *corenr-CORN* did not), the difference in recognition times between the intact and TL versions of the prime actually remained the same for the truly derived and pseudo-derived items (i.e., the RT difference between *hunetr-HUNT* and *corenr-CORN* was the same as that between *hunter-HUNT* and *corner-CORN*). Such an outcome therefore makes it hard to conclude that derived and pseudo-derived words are processed differently when disrupted through letter transposition.

The results reported by Diependaele et al. (2013) are further thrown into doubt by virtue of the fact that an attempt to replicate another of their findings has proven unsuccessful. In particular, Diependaele et al. (2013) reported that suffixed nonwords primed their stem when intact (e.g., *huntal-HUNT*), but not when disrupted through letter transposition (e.g., *hunatl-HUNT*), whereas Taft et al. (2018) observed significant priming for both. The result reported by Diependaele et al. (2013) was consistent with their dual-pathway account, since letter transposition prevents pre-lexical decomposition, which is the only pathway that will allow the stem of a nonword to be activated. Therefore, our finding that *hunatl-HUNT* priming does actually occur is not only problematic for the Diependaele et al. (2013) account, but is consistent with AUSTRAL because pre-lexical decomposition can still take place despite any difficulties in doing so as a result of orthographic disruption.

Conclusion

The AUSTRAL framework provides an explicit answer to the question of how we read polymorphemic words. According to the model, we break complex words down into manageably sized and optimally informative chunks for the purpose of both storage in and retrieval from lexical memory. Such chunks provide structure to all complex words, whether polymorphemic or monomorphemic, though the former especially benefit from the higher frequency of their component morphemes. The localist nature of AUSTRAL allows an explicit description of the way in which any word is recognized, hence generating predictions about the ease of recognizing particular types of words under particular conditions. This is not something that follows naturally from amorphous learning accounts (e.g., Baayen et al., 2011, 2019). Moreover, localist accounts of lexical processing maintain the focus on words as linguistic entities with an interesting internal structure, while the statistical approach relegates words to the status of any object with which humans happen to interact. To my mind, if the latter approach becomes widely adopted, it will sound the death knell for research into the nature of polymorphemic word recognition.

References

Amenta, S., Marelli, M., & Crepaldi, D. (2015). The fruitless effort of growing a fruitless tree: Early morpho-orthographic and morpho-semantic effects in sentence reading. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 41(5), 1587–1596. doi:10.1037/xlm0000104.

Baayen, R. H., Chuang, Y. Y., Shafael-Bajestan, E., & Blevins, J. P. (2019). The discriminative lexicon: A unified computational model for the lexicon and lexical processing in comprehension and production grounded not in (de)composition but in linear discriminative learning. *Complexity*, 2019, 1–39. doi:10.1155/2019/4895891.

Baayen, R. H., Dijkstra, T., & Schreuder, R. (1997). Singulars and plurals in Dutch: Evidence for a parallel dual route model. *Journal of Memory and Language*, 37(1), 94–117. doi:10.1006/jmla.1997.2509.

Baayen, R. H., Milin, P., Filipovic Durdevic, D., Hendrix, P., & Marelli, M. (2011). An amorphous model for morphological processing in visual comprehension based on naive discriminative learning. *Psychological Review, 118*(3), 438–481. doi:10.1037/a0023851.

Bertram, R., Schreuder, R., & Baayen, R. H. (2000). The balance of storage and computation in morphological processing: The role of word formation type, affixal homophony, and productivity. *Journal of Experimental Psychology: Learning, Memory, & Cognition*, 26(2), 489–511. doi:10.1037/0278-7393.26.2.489.

Beyersmann, E., Cavalli, E., Casalis, S., & Colé, P. (2016). Embedded stem priming effects in prefixed and suffixed pseudowords. *Scientific Studies of Reading*, 20(3), 220–230. doi:10.1080/10888438.2016.1140769.

Chateau, D., & Jared, D. (2003). Spelling–sound consistency effects in disyllabic word naming. *Journal of Memory and Language*, 48(2), 255–280. doi:10.1016/S0749-596X(02)00521-1.

Chen, H.-C., & Vaid, J. (2007). Word frequency modulates the Basic Orthographic Syllabic Structure (BOSS) effect in English polysyllable word recognition. *Language and Cognitive Processes*, 21(1), 58–82. doi:10.1080/01690960500372717.

Crepaldi, D., Rastle, K., Coltheart, M., & Nickels, L. (2010). "Fell" primes "fall," but does "bell" prime "ball"? Masked priming with irregularly-inflected primes. *Journal of Memory and Language*, 63(1), 83–99. doi:10.1016/j.jml.2010.03.002.

Diependaele, K., Morris, J., Serota, R. M., Bertrand, D., & Grainger, J. (2013). Breaking boundaries: Letter transpositions and morphological processing. *Language and Cognitive Processes*, 28(7), 988–1003. doi:10.1080/01690965.2012.719082.

Feldman, L. B., O'Connor, P. A., & Moscoso del Prado Martín, F. (2009). Early morphological processing is morpho-semantic and not simply morpho-orthographic: An exception to form-then-meaning accounts of word recognition. *Psychonomic Bulletin & Review*, 16(4), 684–691. doi:10.3758/PBR.16.4.684.

Forster, K. I., & Azuma, T. (2000). Masked priming for prefixed words with bound stems: Does submit prime permit? *Language & Cognitive Processes*, 15(4), 539–562. doi:10.1080/01690960050119698.

Grainger, J., & Beyersmann, E. (2017). Edge-aligned embedded word activation initiates morpho-orthographic segmentation. In B. H. Ross (Ed.), *Psychology of learning and motivation* (Vol. 67) (pp. 285–317). Amsterdam: Academic Press.

Grainger, J., & Ziegler, J. C. (2011). A dual-route approach to orthographic processing. *Frontiers in Psychology*, 2, 54. doi:10.3389/fpsyg.2011.00054.

Hasenäcker, J., Solaja, O., & Crepaldi, D. (2020). Food in the corner and money in the cashews: Semantic activation of embedded stems in the presence or absence of a morphological structure. *Psychonomic Bulletin and Review*, 27(1), 155–161. doi:10.3758/s13423-019-01664-z.

Lima, S. D., & Pollatsek, A. (1983). Lexical access via an orthographic code? The Basic Orthographic Syllabic (BOSS) reconsidered. *Journal of Verbal Learning and Verbal Behavior*, 22(3), 310–332. doi:10.1016/S0022-5371(83)90215-3.

Marelli, M., Amenta, S., Morone, E. A., & Crepaldi, D. (2013). Meaning is in the beholder's eye: Morpho-semantic effects in masked priming. *Psychonomic Bulletin & Review*, 20, 534–541.

McClelland, J. L., & Rumelhart, D. E. (1981). An interactive activation model of context effects in letter perception: Part 1. An account of basic findings. *Psychological Review*, 88(5), 375–407. doi:10.1037/0033-295X.88.5.375.

Milin, P., Feldman, L. B., Ramscar, M., Hendrix, P., & Baayen, R. H. (2017). Discrimination in lexical decision. *PLoS ONE*, 12, e0171935. doi:10.1371/journal.pone.0171935.

Morris, J., Grainger, J., & Holcomb, P. J. (2013). Tracking the consequences of morphoorthographic decomposition using ERPs. *Brain Research*, 1529, 92–104. doi:10.1016/j.brainres.2013.07.016.

Murray, W. S., & Forster, K. (2004). Serial mechanisms in lexical access: The rank hypothesis. *Psychological Review*, 111(3), 721–756. doi:10.1037/0033-295X.111.3.721.

Pastizzo, M. J., & Feldman, L. B. (2004). Morphological processing: A comparison between free and bound stem facilitation. *Brain and Language*, 90(1–3), 31–39. doi:10.1016/S0093-934X(03)00417-6.

Perry, C. (2013). Graphemic parsing and the basic orthographic syllable structure. *Language and Cognitive Processes*, 28(3), 355–376. doi:10.1080/01690965.2011.641386.

Rastle, K., & Davis, M. H. (2008). Morphological decomposition based on the analysis of orthography. *Language and Cognitive Processes*, 23(7–8), 942–971. doi:10.1080/01690960802069730.

Rueckl, J. G. (2010). Connectionism and the role of morphology in visual word recognition. *The Mental Lexicon*, 5(3), 371–400. doi:10.1075/ml.5.3.07rue.

Rumelhart, D. E., & McClelland, J. L. (1982). An interactive activation model of context effects in letter perception: Part 2. The contextual enhancement effect and some tests and extensions of the model. *Psychological Review*, 89(1), 60–94. https://stanford.edu/~jlmcc/papers/RumelhartMcClelland82.pdf.

Schreuder, R., & Baayen, R. H. (1995). Modeling morphological processing. In L. B. Feldman (Ed.), *Morphological aspects of language processing* (pp. 131–154). Hillsdale, NJ: Lawrence Erlbaum Associates Limited.

Seidenberg, M. S., & Gonnerman, L. M. (2000). Explaining derivational morphology as the convergence of codes. *Trends in Cognitive Sciences*, 4(9), 353–361. doi:10.1016/S1364-6613(00)01515-1.

Smolka, E., Preller, K., & Eulitz, C. (2014). "Verstehen" ("understand") primes "stehen" ("stand"): Morphological structure overrides semantic compositionality in the lexical representation of German complex verbs. *Journal of Memory and Language*, 72, 16–36. doi:10.1016/j.jml.2013.12.002.

Taft, M. (1987). Morphographic processing: The BOSS re-emerges. In M. Coltheart (Ed.), *Attention and performance, XII* (pp. 265–279). London: Lawrence Erlbaum Associates Limited.

Taft, M. (1991). *Reading and the mental lexicon*. Hove, UK: Erlbaum.

Taft, M. (1994). Interactive-activation as a framework for understanding morphological processing. *Language and Cognitive Processes*, 9(3), 271–294. doi:10.1080/01690969408402120.

Taft, M. (2001). Processing of orthographic structure by adults of different reading ability. *Language and Speech*, 44(3), 351–376. doi:10.1177/00238309010440030301.

Taft, M. (2003). Morphological representation as a correlation between form and meaning. In E. Assink, & D. Sandra (Eds.), *Reading complex words* (pp. 113–137). Amsterdam: Kluwer.

Taft, M. (2004). Morphological decomposition and the reverse base frequency effect. *Quarterly Journal of Experimental Psychology*, 57(4), 745–765. doi:10.1080/02724980343000477.

Taft, M. (2006). A localist-cum-distributed (LCD) framework for lexical processing. In S. M. Andrews (Ed.), *From inkmarks to ideas: Current issues in lexical processing* (pp. 76–94). Hove, UK: Psychology Press.

Taft, M. (2015). The nature of lexical representation in visual word recognition. In A. Pollatsek, & R. Treiman (Eds.) *Handbook on reading* (pp. 99–113). New York: Oxford University Press.

Taft, M., & Forster, K. I. (1975). Lexical storage and retrieval of prefixed words. *Journal of Verbal Learning and Verbal Behavior*, 14(6), 638–647. doi:10.1016/S0022-5371(75)80051-X.
Taft, M., & Kougious, P. (2004). The processing of morpheme-like units in monomorphemic words. *Brain Language* 90(1–3), 9–16. doi:10.1016/S0093-934X(03)00415-2.
Taft, M., & Krebs-Lazendic, L. (2013). The role of orthographic syllable structure in assigning letters to their position in visual word recognition. *Journal of Memory & Language*, 68(2), 85–97. doi:10.1016/j.jml.2012.10.004.
Taft, M., & Li, J. (2020). A new type of masked form priming: Native vs non-native English speakers. *Studies in Second Language Acquisition*, 43(2), 1–12. doi:10.1017/S0272263120000558.
Taft, M. & Li, S. (2019). It's hard to be talented: What possessional adjectives tell us about lexical representation. *The Mental Lexicon*, 14(1), 124–151. doi:10.1075/ml.18011.taf.
Taft, M., Li, S., & Beyersmann, E. (2018). What cross-morphemic letter transposition in derived nonwords tells us about lexical processing. *Journal of Cognition*, 1(1), 36. doi:10.5334/joc.39.
Taft, M., & Nguyen-Hoan, M. (2010). A sticky stick: The locus of morphological representation in the lexicon. *Language and Cognitive Processes*, 25(2), 277–296. doi:10.1080/01690960903043261.
Taft, M., Xu, J., & Li, S. (2017). Letter coding in visual word recognition: The impact of embedded words. *Journal of Memory and Language*, 92, 14–25. doi:10.1016/j.jml.2016.05.002.
Tsang, Y.-K., & Chen, H.-C. (2013). Early morphological processing is sensitive to morphemic meanings: Evidence from processing ambiguous morphemes. *Journal of Memory and Language*, 68(3), 223–239. doi:10.1016/j.jml.2012.11.003.
Xu, J., & Taft, M. (2015). The effects of semantic transparency and base frequency on the recognition of English complex words. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 41(3), 904–910. doi:10.1037/xlm0000052.

12

VECTOR SPACE MORPHOLOGY WITH LINEAR DISCRIMINATIVE LEARNING

Yu-Ying Chuang, Mihi Kang, Luo Xuefeng and Baayen R. Harald

Introduction

Linear Discriminative Learning (LDL) is the statistical engine implementing the mappings between form and meaning in a computational model of the mental lexicon, the Discriminative Lexicon (DL), laid out in Baayen et al. (2019). Given numeric representations for words' forms and their meanings, the mathematics of multivariate multiple regression are used to transform form vectors into meaning vectors (comprehension), and to transform meaning vectors into form vectors (production). The beta coefficients of the regression models are equivalent to the weights on the connections in fully connected simple networks with input units, output units, and no hidden layers, when these networks are trained to perfection (Chuang et al., 2020a; Shafaei-Bajestan et al., 2021). In other words, the regression coefficients represent the best estimates (in the least squares sense) of the end-state of incremental learning.

Although extremely simple, we have found the DL and its implementations of vector space morphology with LDL surprisingly effective for modeling a wide range of phenomena in lexical processing (see Chuang and Baayen, 2021 for an overview). In what follows, we present three new case studies illustrating the potential of vector space morphology for morphological theory and the study of lexical processing.[1] We first illustrate how LDL can be used to model Korean verb inflection. Our goal here is to show that computationally the algorithms of LDL work for a non-trivial dataset of a language with complex morphology. We then, in our second case study, show how LDL can be used to predict morphological priming in auditory comprehension, using data from Dutch (Experiment 1 of Creemers et al., 2020). Here, our goal is to demonstrate that our approach offers predictive precision at the item level for data that *prima facie* would seem to support theories positing obligatory morphological decomposition as the first step in the lexical processing of complex words. Our third case study addresses the production

DOI: 10.4324/9781003159759-12

of Mandarin words, focusing on acoustic duration in spontaneous speech as response variable. The goal of this final study is to illustrate how measures can be derived from LDL networks that make it possible to enhance prediction accuracy beyond what is possible with standard predictors such as word length in phones and frequency of occurrence. The general discussion provides reflection on the implications of our approach for morphological theory, theories of lexical processing, and the experimental design of studies on morphological processing.

Vector Space Morphology for Korean Verbs

Korean has a complex morphology that challenges linguistic analysis in many ways, even though it is generally described to be agglutinative. The Korean verb system is especially rich. Although there is no agreement about how to best analyze Korean verbs (see Yang, 1994 for a detailed discussion), the seven categories (roughly following Sohn, 2013) listed in Table 12.1 provide an overview of the factors that jointly determine a verb's form.

Subject honorifics express the relative status of the speaker and the subject of the clause. If the subject of the sentence has superior status, the subject typically is an older relative, a stranger, an employer, or a teacher. Addressee honorifics are determined by the degree of intimacy between speaker and interlocutor. They are also referred to as "speech levels." Up to six speech levels have been distinguished in the literature, but in Table 12.1 we only list the four most common ones. The intimate and plain speech levels are usually used among family members and close friends, whereas the polite speech level is adopted when speakers feel the necessity to show politeness to interlocutors. The formal speech level is usually used in formal contexts, such as news broadcasting. The category labeled "mode" comprises a great many nuances that are realized by means of a wide range of exponents. The language has a four-way contrast for different kinds of illocutionary force. Example (1) (Sohn, 2013) presents a sentence with a verb on which all these seven inflectional categories are realized; the numbers refer to the inflectional and derivational dimensions listed in Table 12.1.

TABLE 12.1. Inflectional and derivational dimensions of the Korean verb system. The values in italics pertain to example (1).

derivation	(1)	active (unmarked), causative, *passive*
subject honorifics	(2)	plain (unmarked), *honorific*
tense	(3)	present (unmarked), *past*, future
modality	(4)	neutral (unmarked), volition, *conjecture*
addressee honorifics	(5)	*formal*, polite, intimate, plain
mode	(6)	neutral (unmarked), *retrospective*, epistemic (exlamation, realisation, conjecture, agreement, witness, etc.), intention, wish, regret, vigilance, etc.
illocutionary force	(7)	declarative, *inquisitive*, imperative, propositive

(1) 그 분이 잡히시었었겠습디까?
ku pwun-i cap-hi-si-ess-ess-keyss-sup-ti-kka?
the person-NM catch-(1)-(2)-(3–3)-(4)-(5)-(6)-(7)
"Did you feel (guess) that he had been caught?"

Theories vary in terms of how to decompose Korean verbs into stems and exponents. The segmentation of the inflectional features and their semantic interpretation differ from scholar to scholar. For example, a verbal suffix sequence such as -(스)ㅂ니다 (-(su)pnita) is analyzed as:

1. sup-ni-ta -습니다, formal speech level+indicative mood+declarative (Sohn, 2013);
2. upni-ta -읍니다, formal speech level+declarative (Yang, 1994);
3. up-nita -읍니다, formal speech level+declarative (Choi, 1929, cited by Yang, 1994); and
4. up-ni-ta -읍니다, formal speech level+indicative mood+declarative (Lee, 1989).

Although Korean is generally described as an agglutinative language, the above examples clarify that a strict morpheme-based analysis is not straightforward. Some exponents are clearly fusional, such as -라 (-la) in 만나라 (manna-la), which realizes both the plain speech level and imperative illocutionary force. Other exponents that realize both the plain speech level and illocutionary force are -니 (-ni), -자 (-ca), and -(느)ㄴ다(-(nu)nta). Both stems and exponents may show allomorphy or even suppletion. Thus, the infinitive of the verb "to eat" has two allomorphs, 먹 (mek), and 먹어 (meke). Likewise, -ㄴ다 (-nta, plain speech level, declarative illocutionary force) is found after verb stems ending in vowels, but it appears as -는다 (-nunta) after consonants. Stem suppletion is found for, for example, the verb "to eat," which when used with plain honorific speech requires the allomorph 먹 (mek) but which, when used with subject honorifics, is realized as 드시 (tusi).

The non-trivial morphology of Korean raises the question of whether the simple linear mappings of discriminative learning can actually master this system, without ever having to define morphemes or exponents. To address this question, the present study focuses on verb forms realizing combinations of the four most frequently used inflectional categories: subject honorifics (labeled as "honorifics" in our dataset), tense, speech level, and illocutionary force. The feature values that we implemented are those listed above in Table 12.1. The combinations of these features result in 59 inflected forms for a standard verb. Semantically impossible combinations are not included (e.g., past propositive or future imperative). In this dataset, which in total comprises 27,258 word forms of 462 verbs, words' forms are represented by syllables. These syllables do not necessarily coincide with Hangul characters. Although Hangul characters are designed to represent syllables, due to assimilation, contraction, and resyllabification the spoken forms of words can diverge considerably from the Hangul orthography. We opted for phonological transcriptions that follow the spoken forms. Table 12.2 presents three rows of our dataset, which provides the Hangul written

TABLE 12.2. Three Korean verb forms and their phonological and morphological properties that form the input for modeling with LDL.

Hangul	*Word*	*Lexeme*	*Honorifics*	*Tense*	*Speech level*	*Illocutionary force*
고릅니다	go_rUm_ni_da	gorUda	plain	present	formal	declarative
고릅니까	go_rUm_ni_kka	gorUda	plain	present	formal	inquisitive
고르십시오	go_rU_sip-_syo	gorUda	honorific	present	formal	imperative

form, a phonemic representation with underscores indicating syllable boundaries, an identifier for the verb lexeme, and the feature specifications for honorifics, tense, speech level, and illocutionary force. In our dataset, differences in intonation, which can distinguish between words that are otherwise homophones but that have different illocutionary force, are not yet indicated.

In what follows, we will introduce the main concepts behind LDL step by step, without going into mathematical detail, but providing the code for setting up and running the model using the `JudiLing` package for the Julia language (Luo et al., 2021).[2]

Before starting the actual modeling, we first load the `JudiLing` package and the packages for handling csv files and data frames. The following code snippet assumes that our dataset, `korean.csv`, is available in the current working directory:

```
using JudiLing, CSV, DataFrames
korean = DataFrame(CSV.File("korean.csv"));
```

In order to set up mappings between words' forms and their meanings, we need to define numeric representations for form and meaning. We first consider setting up a matrix with row vectors that represent words' forms. There are many ways in which form vectors can be defined. In the present study, we set up form vectors that specify which pairs of consecutive syllables occur in a word. That is, we build a form matrix ***C*** with as many rows as there are words and with as many columns as there are syllable pairs. We indicate the presence of a syllable pair with 1 and its absence with 0. Constructing this matrix with `JudiLing`'s `make_cue_matrix` function is straightforward:

```
C_obj = JudiLing.make_cue_matrix(korean, grams=2,
                                 target_col=:Word, tokenized=true,
                                 sep_token="_", keep_sep=true);
```

The directive `grams=2` tells the model to construct di-syllables, the directive `target_col` specifies in which column of the dataset word-form information can be found, and the `sep_token` directive specifies that the underscore represents the syllable boundary marker. The output object, `C_obj`, contains several useful data structures, of which the ***C*** matrix (`C_obj.C`) is of interest to us here.

The second modeling step is to construct the matrix ***S*** that represents words' meanings in numeric form as in distributional semantics (Landauer and Dumais, 1997; Mikolov et al., 2013). These vectors can be extracted from corpora using standard methods from computational linguistics. In this study, we simulate these vectors, but we make sure that they properly represent inflectional contrasts (see Baayen et al., 2018; Chuang et al., 2020b for further examples). This is accomplished by summing the simulated semantic vectors of the verb stem and the simulated vectors representing the various inflectional features realized in a given inflected form. Thus, the semantic vector of the first word *go_rUm_ni_da* is obtained by summing the vectors of *gorUda* (Lexeme), *plain* (Honorifics), *present* (Tense), *formal* (Speech Level), and *declarative* (Illocutionary Force).

All elementary simulated semantic vectors consist of random numbers following Gaussian distributions. By adding inflectional vectors to base vectors, the meanings of base words are shifted systematically and in different ways that are specific to the inflectional meanings that are realized in conjunction with that base word. Figure 12.1 illustrates this concept for tense inflection. By adding the vector of past to the vectors of the verbs in the present tense, we move their positions from the area in space where present-tense forms are located to the area where past-tense forms cluster.

Simulating morphologically aware semantic vectors with `JudiLing` is straightforward. All we need to do is specify the dataset, the name of the column in the dataset that provides the verb stems (lexemes), and the names of the columns that specify inflectional feature values. The `ncol` directive specifies the number of columns for ***S***. Here, we set it to be the same as the number of columns of ***C***:

```
S = JudiLing.make_S_matrix(korean, [:Lexeme],
                        [:Honorifics, :Tense, :SpeechLevel,
                        :IllocutionaryForce],
                        ncol=size (C_obj.C, 2);
```

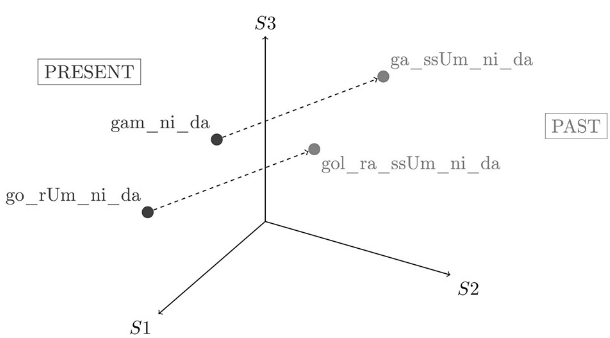

FIGURE 12.1. Vector addition shifts the position of a vector in semantic space. In this example, the vectors of the two verbs in present-tense forms (*gam_ni_da* "to go," *go_rUm_ni_da*, "to pick") are added with the vector of *past*, which moves them from the *present* area to the *past* area.

With $\boldsymbol{C}$ and $\boldsymbol{S}$, we can now proceed to set up the mappings from form to meaning (comprehension) and from meaning to form (production). We first compute the comprehension network $\boldsymbol{F}$, which predicts word meanings from word forms, by solving $\boldsymbol{S} = \boldsymbol{CF}$. `JudiLing`'s function `make_transform_matrix` estimates $\boldsymbol{F}$ in a numerically optimized way:

```
F = JudiLing.make_transform_matrix(C_obj.C, S);
```

The $\boldsymbol{F}$ matrix specifies the connection weights of all the di-syllable cues to all semantic dimensions. In other words, $\boldsymbol{F}$ is a trained network or, equivalently, a multivariate multiple regression model that takes a verb's form vector $\boldsymbol{c}$ as input and predicts its semantic vector $\hat{\boldsymbol{s}}$. Restating this for all words jointly, we obtain the predicted semantic matrix $\hat{\boldsymbol{S}}$ by multiplying $\boldsymbol{C}$ with $\boldsymbol{F}$:

```
Shat = C_obj.C * F;
```

How successful is this mapping from form to meaning? How close are the predicted semantic vectors to the gold standard vectors in $\boldsymbol{S}$? We can evaluate closeness by means of the Pearson correlation, and evaluate the mapping to be successful for a given word i if its predicted semantic vector $\hat{\boldsymbol{s}}_i$ has the highest correlation with the gold standard vector s_i. For the present dataset, we obtain an accuracy of 99%:

```
JudiLing.eval_SC(Shat, S, korean, :Word)
0.9918
```

For modeling production, we first derive the weight matrix $\boldsymbol{G}$, which is associated with the network that maps meanings $\boldsymbol{S}$ to forms $\boldsymbol{C}$. With $\boldsymbol{G}$ in hand, we can then calculate the predicted form matrix $\hat{\boldsymbol{C}}$:

```
G = JudiLing.make_transform_matrix(S, C_obj.C);
Chat = S * G;
```

The $\hat{\boldsymbol{C}}$ matrix specifies for each word the amount of estimated semantic support that the di-syllables receive for that word. Although the $\boldsymbol{G}$ matrix tells us which di-syllables are most likely to be part of a given word, at this point we have no criterion for selecting those di-syllables that actually occur in a given word, and we also have no information about their proper order. However, since di-syllables contain partial information about syllable order, we can weave syllables together. There are several ways in which this can be accomplished. Here, we make use of an algorithm that first learns to predict, for a given word, and for all possible positions, which di-syllable is most appropriate for that position. Given the top candidates, the algorithm then weaves together di-syllables into words, which typically results in several possible word candidates. The algorithm then selects the candidate that, when presented to the comprehension network, best approximates the targeted meaning (Baayen et al., 2019 refer to this as synthesis by analysis). The `learn_paths` function implements this algorithm:

```
res = JudiLing.learn_paths(korean, C_obj, S, F, Chat);
```

We evaluate production accuracy by comparing the predicted forms with the targeted forms. Production accuracy is 90%:

```
JudiLing.eval_acc(res, C_obj)
0.9006
```

What we have shown, for a non-trivial Korean dataset of complex inflected verbs, is that the simple mappings of LDL work with high levels of accuracy for both production and comprehension. Further research will have to clarify whether the model is productive, in the sense that it can also understand and produce inflected verbs that it has not seen during training. As Korean morphology is reasonably systematic, we expect to find decent performance for unseen verbs, just as observed previously for Estonian (Chuang et al., 2020b). Conversely, when modeling German noun paradigms with LDL, Heitmeier et al. (2021) found that the model is not very productive. This is unsurprising, considering the massive irregularities in a system that has been described as "degenerate." In other words, if there is no reasonably systematic alignment between the form and meaning space in a given language, LDL will also fail to understand and produce novel word forms, just as observed for native speakers.

Predicting Comprehension

We have illustrated for Korean that LDL can learn the mappings between form and meaning without requiring stems, morphemes, or exponents. In this section, we investigate whether the model can generate useful predictions for experimental data on lexical processing. Creemers et al. (2020) used the primed auditory lexical decision task to assess processing costs for Dutch complex verbs with initial particles or prefixes. This study observed equivalent priming effects for semantically transparent and semantically opaque verbs, as compared to control conditions, replicating earlier work on German verbs (Smolka and Eulitz, 2018; Smolka et al., 2007). These results dovetail well with theories positing that morphological processing involves the automatic decomposition of forms into their constituents (Lewis et al., 2011; Marantz, 2013; Stockall and Marantz, 2006; Taft, 2004), irrespective of their semantics.

LDL does not decompose visual or auditory input into morphological constituents. Instead, it decomposes its input into finer-grained, overlapping sublexical units such as trigrams, triphones, or syllables (for modeling audio input with LDL, see Shafaei-Bajestan et al., 2021). Since the model sets up simple mappings between sublexical units and semantic vectors, it is *a priori* not self-evident that it can predict priming effects that have been argued to be consistent with obligatory morpho-orthographic decomposition. Baayen and Smolka (2020) addressed this question for German, and showed, using the Naïve Discriminative Learning (NDL) model of Baayen et al. (2011), that priming effects are inversely proportional to the extent that the trigrams in a prime word pre-activate the semantic unit representing the meaning of the target word. The downside of the NDL model is that all word meanings are construed as orthogonal, due to its one-hot encoding of words' meanings, and thus are modeled as completely unrelated semantically. Hence, it might be argued that semantics does not really come into its own in this model, and that the NDL model of Baayen and Smolka (2020) is simply capturing pure form effects. In what follows, we therefore move from NDL to LDL, and apply the latter model to the Dutch complex verbs used in Experiment 1 of Creemers et al. (2020). Importantly, unlike for our Korean dataset, where we simulated semantic vectors, in this modeling study we made use of empirical semantic vectors. If LDL correctly predicts the observed priming effects, then this cannot be due to the model not having access to proper corpus-based word embeddings.

Input for modeling was a set of 7,803 Dutch words selected from the lemma database in CELEX (Baayen et al., 1995). For a word to be included, it had to have a frequency of occurrence exceeding 100 (per 42 million) and have at most two constituents, or it had to be listed as a prime or target in Experiment 1 of Creemers et al. (2020). For the semantic matrix S, we used the 300-dimensional fastText vectors (Grave et al., 2018). The modeling steps are identical to the ones described above. The code is thus provided in the supplementary material, and not repeated here. The comprehension accuracy for the current dataset is at 91%.

In order to model lexical priming, we conceptualize the reader's current semantic state as a pointer to a location in semantic space. An experimental trial can then be seen as beginning with a semantic pointer at the origin of this space. Presentation of the prime moves this pointer to the position in semantic space where the prime's semantic vector is approximately located. We may expect that, when this position is closer to that of the target word, the target word is primed more strongly. We evaluated closeness with the correlation measure. For all prime–target pairs, we calculated the correlation r_{ij} of the predicted vector for prime word i and the gold standard vector for target word j. In what follows, we refer to these correlations as prime-to-target approximations (PTAs).

Figure 12.2 shows that these correlations capture the priming effects reported by Creemers et al. (2020). As expected, greater values of PTAs predict shorter RTs. The correlation between PTA and mean by-item log-transformed reaction time was -0.3 ($t(141) = -3.67$, $p = 0.0003$). It is clear that LDL succeeds in modeling morphological priming data, replicating the results of Baayen and Smolka (2020) (see also Milin et al., 2017).

This simulation demonstrates that morphological priming effects can be accounted for by a model that capitalizes on form–meaning relations without any having to rely on hierarchically ordered layers of representations with units representing stems, affixes, and lemmas. Although theories such as those of Crepaldi et al. (2010) provide insightful explanations for a variety of priming effects, the success of these explanations does not prove that their model is correct, just as the present success of our LDL model does not prove that it is correct. As always in science, adjudication between rival

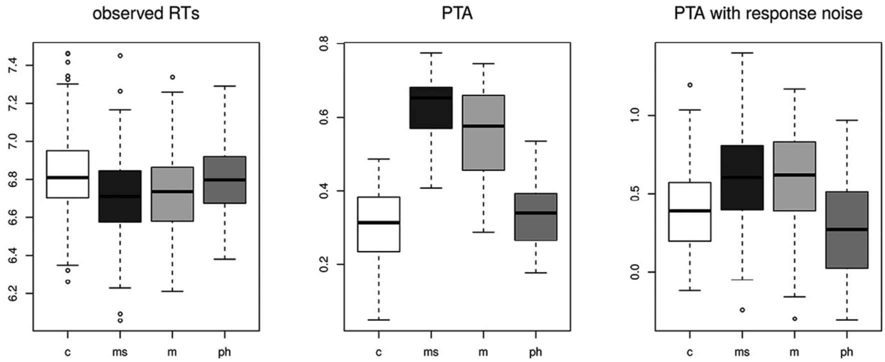

FIGURE 12.2. Distributions of empirical reaction times (left), prime-to-target approximations (center), and prime-to-target approximations with N(0, 0.3) response noise added (right). (c: control primes, ms: morphologically and semantically related primes, m: morphologically related but semantically unrelated primes, ph: phonologically related primes.)

theories has to proceed on the basis of evaluations of prediction accuracy, learnability, scalability to large datasets, and the amount of hand-crafting and tuning of parameters required to get a computational model to work. Such an adjudication is beyond the scope of this chapter; all we say here is that there is a simple alternative explanation for priming effects that are traditionally understood as evidence for obligatory morphological decomposition.

Predicting Production

One measure that is currently informing theories of speech production is words' acoustic durations (Gahl, 2008; Plag et al., 2017). In this study, we investigated the acoustic durations of words in Taiwan Mandarin. From a corpus of spontaneous Taiwan Mandarin speech (Fon, 2004), we selected 7,349 one- to five-syllable words for which fastText semantic vectors are available. We built the production model with triphones, the code of which is again provided in the supplementary material.

From this model, we derived two novel measures. The first measure is derived from the production weight matrix **G**, which has semantic dimensions on rows and triphones on columns. The column vectors of **G** quantify the extent to which triphones contribute to realizing the meanings of their carrier words. To make this more concrete, consider an example lexicon with just four English words: *tree, bee*, and their plural forms *trees, bees*. The model setup is presented in Table 12.3: for cues, we used diphones, and their semantic vectors, using simulated vectors, are the sum of their respective base word vector (TREE/BEE) and number vector (SG/PL). Following the same procedure as described above, we obtained the **G** matrix, the production network mapping meanings onto forms. Table 12.4 presents the column vectors of **G** for the word *trees*, together with a vector of zeroes representing the origin.

TABLE 12.3. Example lexicon with four words. The second and third columns specify words' diphones and how their semantic vectors are constructed.

Word	*diphones*	*semantics*
tree	#t_tr_ri_i#	TREE + SG
bee	#b_bi_i#	BEE + SG
trees	#t_tr_ri_iz_z#	TREE + PL
bees	#b_bi_i#	BEE + PL

TABLE 12.4. Cue weights in the production network **G** for diphones required to produce *trees*. The bottom row indicates pair-wise Euclidean distances between diphone vectors, starting from the origin (all-zero vector) to the last diphone of the word.

	origin	#t	tr	ri	iz	z#
S1	0	-0.01	-0.01	-0.01	-0.03	-0.03
S2	0	-0.06	-0.06	-0.06	-0.11	-0.11
S3	0	0.05	0.05	0.05	0.04	0.04
S4	0	0.07	0.07	0.07	0.03	0.03
S5	0	-0.02	-0.02	-0.02	0.01	0.01
S6	0	0.00	0.00	0.00	-0.02	-0.02
S7	0	-0.07	-0.07	-0.07	0.00	0.00
S8	0	-0.05	-0.05	-0.05	-0.01	-0.01
distance		0.137	0	0	0.143	0

For visualization, we projected the high-dimensional space of ***G*** onto a two-dimensional surface by applying principal component analysis to the column vectors of ***G***. Figure 12.3 shows that the stem diphones of *tree* (`#t`, `tr`, `ri`) all appear together on the left, whereas the stem diphones of bee (`#b`, `bi`) cluster in the circle on the right. Interestingly, the diphone `i#`, on the one hand, and those of `iz` and `z#`, on the other, also are located in two different positions: at the top and bottom, respectively. Such topological organizations of a network can also be obtained by other methods (see, e.g., Ferro et al., 2011; Heitmeier and Baayen, 2020).

To understand why the diphones cluster in this way, we have to look at the column vectors of ***G*** (henceforth "diphone vectors"). Since the diphone vectors share the same dimensions as the semantic vectors, we can examine how they are semantically related by calculating the pair-wise correlations of the diphone vectors and the vectors of all base words and inflectional meanings—TREE, BEE, SG, PL, referred to as lexomes in Baayen et al. (2019). The resulting correlation matrix is presented in Table 12.5. The diphones of *tree* are best correlated with the vector of TREE, and the diphones of *bee* are best correlated with the vector of BEE. Furthermore, `i#` is strongly correlated with the SG vector, whereas `iz` and `z#` correlate well with the PL vector. The correlations in bold in Table 12.5 can therefore

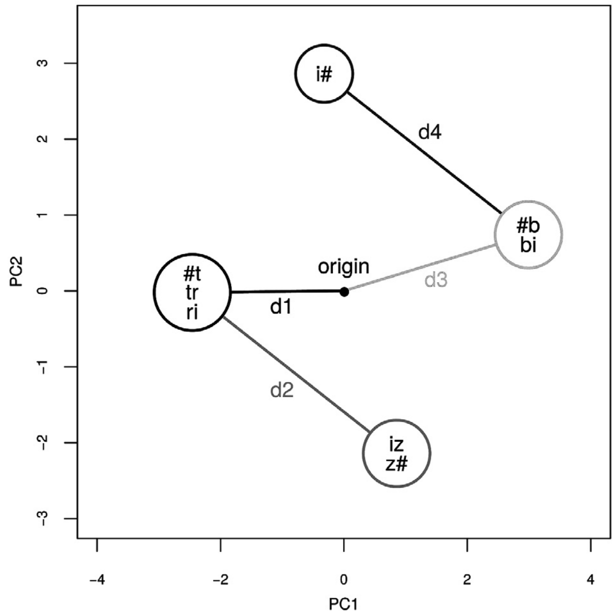

FIGURE 12.3. Projection of diphone vectors onto a two-dimensional plane using principal component analysis. For *trees*, the total Distance Traveled is d1 + 0 + 0 + d2 + 0 (see also Table 12.4).

TABLE 12.5. Correlations of the diphone vectors in ***G*** and the semantic vectors of the base word and number lexomes. The highest correlation in each row is highlighted in bold.

	TREE	*BEE*	*SG*	*PL*
#t tr ri	**0.55**	-0.44	0.26	0.13
#b bi	-0.42	**0.72**	0.15	0.28
i#	0.04	0.19	**0.85**	-0.17
iz z#	0.11	0.18	-0.29	**0.68**

be understood as measuring the functional load of the diphones. In this example, `i#` realizes primarily singular number, `z#` realizes plural number, and `#b` and `bi` realize the base meaning of BEE.[3] It is surprising how well the network succeeds in figuring out, for this agglutinative example, which bits of form have what purpose without ever having to tell the model explicitly about stems and exponents.[4]

Is lexical processing, specifically durations of word production in this study, influenced by the topological organization of diphones? We reasoned that, when diphones have very similar functional load, the costs of evaluating their contribution to production is smaller than when diphones are at greater distance from each other. This hypothesis leads to our first measure for predicting acoustic durations, the total distance traveled in semantic space when tracing a word's successive diphones (henceforth "`Distance Traveled`"). Consider again Table 12.4, which arranges the diphones in the order in which they drive articulation. Assuming that we start from the null meaning (represented by the origin, an all-zero vector), we can calculate the Euclidean distance from one successive diphone vector to the next, as indicated in the last row of the table. From the origin to the vector of `#t`, this distance is 0.137. In Figure 12.3, this distance is labeled as **d1** in green. From `#t` to `tr`, and from `tr` to `ri`, the distance is zero: these three diphones are associated with the TREE meaning to the same extent, and have the same location in Figure 12.3. Hence for these diphones, no further distance penalty is incurred. However, for the next transition, as `iz` is located further down in the plane, we obtain a non-zero distance (**d2** in Figure 12.3). Finally, `z#` is in the same position as `iz`, hence the distance between the last two diphones is zero. The total distance traveled for *trees* is 0.137 (d1) + 0 + 0 + 0.143 (d2) + 0 = 0.28. The larger the value of Distance Traveled, the more heterogeneous the diphone vectors are, the more variegated the meanings are that they have to realize, and the lower the within-word semantic coherence is. These considerations lead us to expect that acoustic duration and Distance Traveled are positively correlated: more complex messages require longer codes (cf. Kuperman et al., 2009).

The second measure that we considered for predicting acoustic durations is much simpler. As illustrated above, the learning algorithm that orders triphones for articulation (implemented in the `learn_paths` function) predicts, for a given word and a specific triphone position (ranging from 1 to the length of the longest word in the dataset), how well the different possible triphones are supported for that position. For example, for the Mandarin word 土地 (tǔdì) "land," the positional triphone support for the first triphone `#tu` is 0.04 for position 1, and that for the second triphone `tud` is 0.03 for position 2. Our second measure, `Triphone Support`, is the sum of the positional supports for a word's triphones. The larger the value of Triphone Support, the more confident the model is in terms of its prediction. We therefore expect that Triphone Support and acoustic duration enter into a positive correlation with one another.

Are these two measures indeed predictive for words' acoustic durations? We first fitted a generalized additive model (GAM) (Wood, 2017) to the acoustic durations with word frequency and word length (number of phones) as predictors. Both frequency and length are strong predictors, unsurprisingly. The effect of word length is rather trivial, as all we are doing is regressing duration in milliseconds on duration in phones. The reason we include length is to ensure that our model-based measures cannot simply be reduced to word length. In other words, this model serves as our baseline model.

When Distance Traveled and Triphone Support were added as predictors to the baseline model, goodness of fit improved substantially by no less than 256 AIC units. This clarifies that the distance and support measures capture properties in production that cannot be fully accounted for by word length and frequency. Unfortunately, due to substantial collinearity, the resulting model suffers from suppression and enhancement, rendering interpretation impossible. Both our model-based measures are highly correlated with word length: for Distance Traveled, $r = 0.72$, $p < 0.0001$; and for Triphone

Support, $r = 0.37$, $p < 0.0001$. In order to obtain a model that is better interpretable, we first regressed word length on the distance and support measures. This was achieved by fitting another GAM to word length with the two LDL measures as predictors. The R-squared of this model was 49%. The correlation of the residuals of this model, henceforth "`Residualized Length`," with the original word length measure was 0.68.

We then refitted the GAM, replacing word length with Residualized Length. The mid and right panels of Figure 12.4 plot the effects of frequency and length. Words with higher frequency have shorter durations, and longer words are produced with longer durations, as expected. What is more interesting is the interaction of the two LDL measures, as presented in the left panel. We observed a strong effect of Distance Traveled: word durations became longer with increasing Distance Traveled. This suggests that when a word's triphones are far apart in semantic space, in which case they jointly realize more complex semantics, then the speed with which this word is articulated is slowed, reflecting greater processing costs. With regard to Triphone Support, there is a crossover effect. For small values of Distance Traveled, the larger the support, the longer the durations. For large values of Distance Traveled, however, the trend is reversed: here, durations become shorter with increasing Triphone Support. However, the reversed trend should be considered with caution, due to data sparsity in this region.

General Discussion

The three case studies that we have reported illustrate why we find it fruitful to rethink morphology in terms of mappings between form and meaning spaces, using the toolkit of linear algebra and regression modeling. Although firmly rooted in Word and Paradigm Morphology, our analysis of how triphones may be topologically clustered (when projected onto a two-dimensional space) suggests that, when a morphological system is agglutinative, clusters of triphones start to look very much like stems and exponents. If

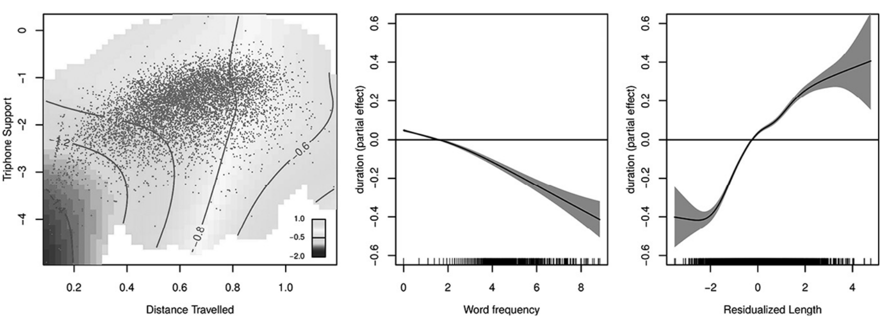

FIGURE 12.4. The interaction effect of Distance Traveled and Triphone Support on mean acoustic durations of Mandarin words produced in spontaneous speech (left panel). Lighter colors represent longer durations, and grey dots indicate the distribution of data points. The effects of word frequency and Residualized Length are presented in the middle and right panels.

this finding generalizes from a toy example to realistic datasets, it would provide a bridge between Word and Paradigm Morphology and decompositional theories, which have made connections with neuroimaging studies suggesting that constituents are subserved by localized cell-assemblies in the brain (Bozic et al., 2007; Chersi et al., 2014; Lewis et al., 2011). At the same time, it is clear that for claims about the neurobiological reality of classical discrete morpheme and stem representations to be convincing it will be necessary to show that there is no confound between the classical units and sublexical units such as triphones. Likewise, when designing priming studies to support the hypothesis of obligatory automatic morphological decomposition, it will be necessary to control for the kind of low-level variables that this study has shown to co-determine lexical processing, the reason being that patterns of priming may already emerge straightforwardly from a language's distributional properties with respect to form, meaning, and the mapping between the two. The point we make here is not new (see, e.g., Seidenberg and Gonnerman 2000). What *is* new is that this point can be made with the simplest possible network, and the simplest possible mathematics, while retaining full transparency of interpretation. Our model offers *interpretable* machine learning.

Breiman (2001) famously made a distinction between two very different cultures for data analysis, contrasting statistical modeling with machine learning. Whereas machine learning is optimized for obtaining precise predictions that can be profitably put to use in industry, statistical modeling is concerned with understanding the data and to this end builds models that could have generated the data. LDL is closer in spirit to statistical modeling than to machine learning. It capitalizes on simplicity, in the hope that this will contribute to further clarity of understanding. Undoubtedly, this simplicity comes at a cost. Although many mappings in morphology thus far have appeared to be well approximated by linear mappings, nonlinear mappings are likely to offer further precision. Interestingly, the words for which LDL lacks precision are the words that are likely to be more difficult to learn also for human learners and that hence will have greater lexical-processing costs in the mental lexicon. George Box (1976) is well known for stating that all statistical models are wrong but some are useful. In the same way, even though vector space morphology as implemented with LDL requires many simplifying assumptions, it nevertheless provides a useful tool for probing the mental lexicon.

Notes

1 The data and code for the three case studies are available at https://osf.io/w6z3q/.
2 For installation of the package, see the online manual at https://megamindhenry.github.io/JudiLing.jl/stable/#Installation.
3 These correlations clarify how those diphones are selected for production that properly realize words' semantics. When we calculate the dot product of a row vector s_i of $\boldsymbol{S}$ (the sum of lexome vectors) and a diphone column vector g_j of $\boldsymbol{G}$, we multiply their elements pairwise and then sum. When the two vectors are uncorrelated, this sum will be close to zero. However, when the two vectors are correlated, the dot product will tend to produce larger values. As a consequence, correlated vectors ensure that the support for a diphone in a word's predicted form vector $\hat{\boldsymbol{c}}$ will be greater.

4 For the present agglutinative example, we see clusters of diphones for the two stems and the plural exponent, but the reader should be warned that for realistically sized datasets, and especially for languages with fusional morphology, such crisp and clear divisions of labor are not to be expected. Nevertheless, some albeit more diffuse clustering may still be visible.

References

Baayen, R. H., Chuang, Y.-Y., and Blevins, J. P. (2018). Inflectional morphology with linear mappings. *The Mental Lexicon*, 13(2): 232–270. doi:10.1075/ml.18010.baa.

Baayen, R. H., Chuang, Y.-Y., Shafaei-Bajestan, E., and Blevins, J. (2019). The discriminative lexicon: A unified computational model for the lexicon and lexical processing in comprehension and production grounded not in (de)composition but in linear discriminative learning. *Complexity*, 2019(1), 1–39. doi:10.1155/2019/4895891.

Baayen, R. H., Milin, P., Filipović Durdević, D., Hendrix, P., and Marelli, M. (2011). An amorphous model for morphological processing in visual comprehension based on naive discriminative learning. *Psychological Review*, 118(3): 438–482. doi:10.1037/a0023851.

Baayen, R. H., Piepenbrock, R., and Gulikers, L. (1995). *The CELEX lexical database (CD-ROM)*. Philadelphia: Linguistic Data Consortium, University of Pennsylvania.

Baayen, R. H. and Smolka, E. (2020). Modelling morphological priming in German with naive discriminative learning. *Frontiers in Communication*, 5(17). doi:10.3389/fcomm.2020.000.

Box, G. E. P. (1976). Science and statistics. *Journal of the American Statistical Association*, 71 (356): 791–799. doi:10.2307/2286841.

Bozic, M., Marslen-Wilson, W. D., Stamatakis, E. A., Davis, M. H., and Tyler, L. K. (2007). Differentiating morphology, form, and meaning: neural correlates of morphological complexity. *Journal of Cognitive Neuroscience*, 19(9): 1464–1475. doi:10.1162/jocn.2007.19.9.1464.

Breiman, L. (2001). Statistical modeling: the two cultures (with comments and a rejoinder by the author). *Statistical Science*, 16(3): 199–231. doi:10.1214/ss/1009213726.

Chersi, F., Ferro, M., Pezzulo, G., and Pirrelli, V. (2014). Topological self-organization and prediction learning support both action and lexical chains in the brain. *Topics in Cognitive Science*, 6(3): 476–491. doi:10.1111/tops.12094.

Choi, H.-B. (1929) (Reprinted in 1989). *Uli Mal Pon[Our Grammar]*. Seoul: Chong Um Sa.

Chuang, Y.-Y. and Baayen, R. H. (2021). Discriminative learning and the lexicon: NDL and LDL. In M. Aronoff (Ed.) *Oxford Research Encyclopedia of Linguistics*. Oxford: Oxford University Press.

Chuang, Y.-Y., Bell, M. J., Banke, I., and Baayen, R. H. (2020a). Bilingual and multilingual mental lexicon: a modeling study with linear discriminative learning. *Language Learning*, 71(S1): 219–292. doi:10.1111/lang.12435.

Chuang, Y.-Y., Lõo, K., Blevins, J. P., and Baayen, R. H. (2020b). Estonian case inflection made simple: A case study in Word and Paradigm morphology with Linear Discriminative Learning. In L. Körtvélyessy and P. Štekauer, (Eds.), *Advances in Morphology* (pp. 119–141). Cambridge: Cambridge University Press.

Creemers, A., Davies, A. G., Wilder, R. J., Tamminga, M., and Embick, D. (2020). Opacity, transparency, and morphological priming: a study of prefixed verbs in Dutch. *Journal of Memory and Language*, 110, 104055. doi:10.1016/j.jml.2019.104055.

Crepaldi, D., Rastle, K., Coltheart, M., and Nickels, L. (2010). "Fell" primes "fall," but does "bell" prime "ball"? Masked priming with irregularly-inflected primes. *Journal of Memory and Language*, 63(1): 83–99. doi:10.1016/j.jml.2010.03.002.

Ferro, M., Marzi, C., and Pirrelli, V. (2011). A self-organizing model of word storage and processing: implications for morphology learning. *Lingue e linguaggio*, 10(2): 209–226.

http://www.ilc.cnr.it/~ferro/publications/A_self_organizing_model_of_word_storage_and_processing__implications_for_morphology_learning.pdf.
Fon, J. (2004). *A preliminary construction of Taiwan Southern Min spontaneous speech corpus*. Technical Report NSC-92–2411-H-003–050. Taipei, Taiwan: National Science Council.
Gahl, S. (2008). Time and thyme are not homophones: the effect of lemma frequency on word durations in spontaneous speech. *Language*, 84(3): 474–496. doi:10.1353/lan.0.0035.
Grave, E., Bojanowski, P., Gupta, P., Joulin, A., and Mikolov, T. (2018). Learning word vectors for 157 languages. In N. Calzolari, K. Choukri, C. Cieri, T. Declerck, S. Goggi, K. Hasida, H. Isahara, B. Maegaard, J. Mariani, H. Mazo, A. Moreno, J. Odijk, S. Piperidis, and T. Tokunaga. *Proceedings of the International Conference on Language Resources and Evaluation*. Miyazaki, Japan: European Language Resources Association.
Heitmeier, M. and Baayen, R. H. (2020). Simulating phonological and semantic impairment of English tense inflection with Linear Discriminative Learning. *The Mental Lexicon, 15*(3): 384–421. doi:10.1075/ml.20003.hei.
Heitmeier, M., Chuang, Y.-Y., and Baayen, R. H. (2021). Modeling morphology with linear discriminative learning: considerations and design choices. *Frontiers in Psychology*, 12 (720713). doi:10.3389/fpsyg.2021.720713.
Kuperman, V., Schreuder, R., Bertram, R., and Baayen, R. H. (2009). Reading of multimorphemic Dutch compounds: towards a multiple route model of lexical processing. *Journal of Experimental Psychology: Human Perception and Performance*, 35(3): 876–895. doi:10.1037/a0013484.
Landauer, T. and Dumais, S. (1997). A solution to Plato's problem: the latent semantic analysis theory of acquisition, induction and representation of knowledge. *Psychological Review*, 104(2): 211–240. doi:10.1037/0033-295X.104.2.211.
Lee, H. B. (1989). *Korean Grammar*. New York: Oxford University Press.
Lewis, G., Solomyak, O., and Marantz, A. (2011). The neural basis of obligatory decomposition of suffixed words. *Brain and Language*, 118(3): 118–127. doi:10.1016/j.bandl.2011.04.004.
Luo, X., Chuang, Y.-Y., and Baayen, R. H. (2021). Judiling: an implementation in Julia of Linear Discriminative Learning algorithms for language modeling. https://megamindhenry.github.io/JudiLing.jl/stable/.
Marantz, A. (2013). No escape from morphemes in morphological processing. *Language and Cognitive Processes*, 28(7): 905–916. doi:10.1080/01690965.2013.779385.
Mikolov, T., Sutskever, I., Chen, K., Corrado, G. S., and Dean, J. (2013). Distributed representations of words and phrases and their compositionality. In C. J. C. Burges, L. Bottou, M. Welling, Z. Ghahramani, and K. Q. Weinberger (Eds.), *Proceedings of the 26th International Conference on Neural Information Processing Systems* (Vol. 2) (pp. 3111–3119). Red Hook, NY: Curran Associates.
Milin, P., Feldman, L. B., Ramscar, M., Hendrix, P., and Baayen, R. H. (2017). Discrimination in lexical decision. *PLoS ONE*, 12(2): e0171935. doi:10.1371/journal.pone.0171935.
Plag, I., Homann, J., and Kunter, G. (2017). Homophony and morphology: the acoustics of word-final S in English. *Journal of Linguistics*, 53(1): 181–216. doi:10.1017/S0022226715000183.
Seidenberg, M. S. and Gonnerman, L. M. (2000). Explaining derivational morphology as the convergence of codes. *Trends in Cognitive Sciences*, 4(9): 353–361. doi:10.1016/S1364-6613(00)01515-1.
Shafaei-Bajestan, E., Tari, M. M., and Baayen, R. H. (2021). LDL-AURIS: a computational model, grounded in error-driven learning, for the comprehension of single spoken words. *Language, Cognition and Neuroscience*, 1–28. doi:10.1080/23273798.2021.1954207.
Smolka, E. and Eulitz, C. (2018). Psycholinguistic measures for German verb pairs: Semantic transparency, semantic relatedness, verb family size, and age of reading acquisition. *Behavior Research Methods*, 50(4): 1540–1562. doi:10.3758/s13428-018-1052-5.

Smolka, E., Zwitserlood, P., and Rösler, F. (2007). Stem access in regular and irregular inflection: evidence from German participles. *Journal of Memory and Language*, 57(3): 325–347. doi:10.1016/j.jml.2007.04.005.

Sohn, H. M. (2013). *Korean, Volume 4*. Seoul: Korea University Press.

Stockall, L. and Marantz, A. (2006). A single route, full decomposition model of morphological complexity: MEG evidence. *The Mental Lexicon*, 1(1): 85–123. doi:10.1075/ml.1.1.07sto.

Taft, M. (2004). Morphological decomposition and the reverse base frequency effect. *The Quarterly Journal of Experimental Psychology*, 57A: 745–765. doi:10.1080/02724980343000477.

Wood, S. N. (2017). *Generalized Additive Models*. New York: Chapman & Hall.

Yang, B. S. (1994). *Morphosyntactic phenomena of Korean in role and reference grammar: psych-verb constructions, inflectional verb morphemes, complex sentences, and relative clauses*. PhD thesis, State University of New York at Buffalo.

13

THE ROLE OF PHONOLOGY IN MORPHOLOGICAL ACQUISITION

Ben Davies and Katherine Demuth

The Role of Phonology in Morphological Acquisition

Long before acquiring their first words or morphemes, children are analysing the acoustic patterns in the speech signal and building representations of the *phonology* of their language. Starting from inside the womb, babies become attuned to the rhythm of their ambient language and develop a sensitivity to the stress patterns of words and phrases (Ramus et al., 1999). Before their first birthday, children have robust representations of the discrete sounds in their language (i.e. segments/phonemes; Kuhl, 2004) and know what sound combinations can and cannot constitute a word (i.e. phonotactics; see Jusczyk, 1997).

Children's sensitivity to prosodic stress patterns (Cutler & Norris, 1988) and their understanding of phonotactic constraints (Mattys et al., 1999) allow them to extract discrete words and morphemes from a continuous, noisy acoustic signal. Their early representations of phonology must thus encompass many levels of the sound organisation present within a language. While much research has focussed on the acquisition of individual segments, children must also acquire phonological representations at the levels of the mora, syllable, foot, prosodic word and the even larger phonological phrase, as illustrated by the Prosodic Hierarchy (Nespor & Vogel, 1986; Selkirk, 1984, 1996; Figure 13.1). Yet, while their early understanding of phonology plays a vital role in acquiring lexical and grammatical representations, children's early productions are not always like that of adults. Indeed, many of the common idiosyncrasies observed in early speech – such as segment, morpheme, syllable and grammatical function word omissions – can be better explained by children's still-developing phonology than by deficits in their knowledge of the lexicon or morphosyntax.

DOI: 10.4324/9781003159759-13

Utt	(Phonological Utterance)	*I hope we find some bananas*
IP	(Intonational Phrase)	*I like bananas*
PP	(Phonological Phrase)	*like bananas*
PW	(Phonological/Prosodic Word)	*bananas*
Ft	(Foot)	*nanas*
σ	(Syllable)	*nas*
μ	(Mora)	*na*

FIGURE 13.1. The Prosodic Hierarchy

When children start producing inflectional morphemes in their everyday speech, such as the plural (e.g. *dog**s***) or the past tense (e.g. *walk**ed***), they are typically inconsistent. Sometimes a morpheme is produced, yet at other times it is omitted altogether (Brown, 1973). Similarly, children may produce one particular form of a morpheme (i.e. allomorph), such as the plural ***s*** /-s/ on *cat**s*** /kæts/, but not others, such as plural ***es*** /-əz/ on *buss**es*** /bɐssəz/ (Berko, 1958). Entire function words can also be variably omitted, such as the determiners *a* and *the* in English (Demuth & McCullough, 2009; Gerken, 1996), or *le, la* and *les* in French (Demuth & Tremblay, 2008), or filler syllables inserted in place of a pronoun or auxiliary verb (e.g. '*a go now*' instead of '*I'm going now*') (Peters, 1983; Veneziano & Sinclair, 2000). While some hypothesise that phenomena such as these can be explained by impoverished syntactic (e.g. Radford, 1990; Wexler, 1994) or semantic (Hyams, 2007) representations, it is becoming increasingly clear that phonology plays a large role in many of the common 'omission errors' observed in children's early speech. Factors such as the phonological complexity of a word (Song et al., 2009), where the word occurs within the phonological phrase (Demuth & McCullough, 2009; Demuth & Tremblay, 2008; Gerken, 1996) or where it occurs within an utterance (Hsieh et al., 1999; Mealings & Demuth, 2014; Song et al., 2009; Theodore et al., 2011), can greatly influence the probability of a particular grammatical morpheme being produced. For example, English articles are more likely to be produced when they occur as part of a foot, where they can form part of a prosodic word (e.g. [hit the]$_{FT}$ [ball]$_{FT}$ vs. [catches]$_{FT}$ the [ball]$_{FT}$) (Demuth & McCullough, 2009; Gerken, 1996).

Phonological factors also affect children's *comprehension* of language. Children are better able to perceive inflectional morphemes when they appear at the end of an utterance as opposed to in the middle (Sundara et al., 2011), with comprehension of some allomorphs earlier than others (Davies et al., 2017). This in turn may play a role in terms of when different allomorphs come to be used productively in everyday speech, suggesting a tighter link between perception/comprehension and production than often assumed (see Sundara et al., 2011 for discussion).

Findings such as the above raise questions about the role that children's phonological representations play in their developing morphosyntax and about the relationship between early phonological and morphological systems. The Prosodic Licensing Hypothesis (Demuth, 2014; Demuth & McCullough, 2009), outlined below, is the first step towards establishing an explanatory framework for understanding how interactions between different levels of phonological representation can affect children's surface realisation of morphosyntax. Other factors, such as the frequency of a grammatical morpheme, its perceptual salience, and utterance length/complexity are also discussed. Critical to this discussion is the fact that grammatical function words are all morphemes: these may be written as 'separate words', such as articles, auxiliary verbs, and pronouns, or they may be realised as suffixes, prefixes, and infixes, depending on the morpheme and language. However, even when orthographically written as separate 'words', these function morphemes generally have the phonological status of prosodic clitics. That is, grammatical function morphemes typically cannot stand alone: they are generally unstressed and prosodically group together with words to the right or left, depending on the prosodic context and the language. Below, we examine the acquisition of two different types of grammatical morphemes with different prosodic structures: (1) articles – which prosodify to the right or left, depending on the prosodic context and language; and (2) plural allomorphs, which suffix to the noun.

Prosodic Effects on the Acquisition of Articles

As noted above, researchers have long been aware that children tend to omit grammatical function words/morphemes in their early speech, going from a one-word stage of development (e.g. '*Dog*'), to a two-word stage of development (e.g. '*Want dog!*'), to gradually including function words such as pronouns, articles and auxiliary verbs (e.g. '*I want the dog!*'). Thus, children's early utterances before the age of 2 often tend to contain primarily open-class lexical items such as nouns, verbs and adjectives. That is, children's early speech tends to include words that have semantic content, but only later do they begin to contain more abstract, closed-class function words that may encode information about person, number, tense, aspect, mood, etc. It is thus perhaps not surprising that Brown (1973) proposed that semantic factors governed the emergence of function words.

Note, however, that closed-class items are also much more frequent than open-class words, and Zipf (1932) was one of the first to show that higher-frequency words tend to be shorter (i.e. have less phonetic content). Thus, function words tend to be unstressed, often reduced to one syllable, and may contain reduced vowels (as is the case for the English articles *a* /ə/ and *the* /ðə/ – both of which contain the reduced, unstressed vowel schwa). Thus, it is not just the semantics of these early omitted words that may pose a challenge to acquisition, but also the phonology, since they consist of short/reduced forms without stress. Furthermore, it is not clear that semantics can really predict the course of acquisition of grammatical morphemes. For example, is present tense (3rd person singular -s) really more semantically complex than the past tense (-ed)? If anything, the latter is more 'regular', but it is also much lower in frequency, probably leading to its later acquisition. Likewise, the segmental allomorphs (e.g. *cat+s, dog+z*) before the plural are acquired before the syllabic allomorph (e.g. *bus+es*), yet the semantics is consistent. Yet again, it seems that several factors interact to determine how and when different grammatical morphemes are acquired.

A Perception Problem?

This has raised questions about whether grammatical function words are even perceived: if not, this might account for their omission. Although this is an area of ongoing research, there are some indications that children have no problem perceiving these words. For example, early work by Gerken and McIntosh (1993) showed that children below the age of 2, who do not systematically produce articles, are 'aware' of these elements and their phonological form. This is evidenced by a difference in looking times when a real article is replaced with a 'nonce' article. Thus, even before young children consistently produce articles they 'know' that they are there. This has also been shown to be the case with verbal inflection such as 3rd person singular -s (e.g. '*Now she *walk/walks*') (Soderstrom et al., 2007; Sundara et al., 2011), and cross-linguistically (e.g. French function words: Shi & Gauthier, 2005). This suggests that, at least in some cases, children have a perceptual representation of various types of grammatical morphemes, but that their productions may lag behind. The question is, why?

A Prosodic Account of the Variable Production of Articles

As noted above, it has long been observed that children's production of grammatical morphemes can initially be extremely variable. Gerken and McIntosh (1993) and Gerken (1996) were among the first to experimentally show that 2;3-year-olds were much more likely to produce articles in certain prosodic contexts – for example, when preceded by a monosyllabic vs. a disyllabic verb. This suggests that children are more likely to produce grammatical morphemes when the article can prosodify as part of a disyllabic foot with the previous word (e.g. '*Tom [likes the] [cherry]*') compared to when it remains unfooted (e.g. '*Tom [wanted] the [cherry]*'). Demuth and McCullough (2009) then showed that these unfooted articles are omitted for several months in children's spontaneous speech, long after they are systematically using articles in footed contexts. Gerken (1996) and Demuth and McCullough (2009) suggest that the eventual use of these unfooted articles coincides with children's acquisition of the higher levels of the Prosodic Hierarchy (e.g. access to the level of the Intonational Phrase (IP) – refer to Figure 13.1, above). Once children can handle these higher levels of prosodic structure, around the age of 2;6–3;0, they begin to produce these unfooted articles with greater accuracy.

The fact that similar phenomena are found cross-linguistically suggests that these patterns are quite robust and may apply to other grammatical morphemes as well. For example, it had long been noted that children learning the Bantu language Sesotho would often omit noun-class prefixes until the age of 2;6–3;0 (Demuth, 1992). Closer examination, however, revealed that this was due to prosodic constraints: children had no problems producing monosyllabic words preceded by a noun-class prefix, resulting in a disyllabic foot (e.g. *mo-tho* 'person'), but would systematically omit the same prefix when it occurred before a disyllabic word (e.g. *mo-sadi* 'woman'), that is, when it fell outside the disyllabic foot (Demuth & Ellis, 2009). Note here that the prefix prosodifies with the lexical item to the right – unlike in English, which prosodifies to the left if it can (i.e. when preceded by a monosyllabic word). Similarly, young children acquiring the Oto-Pamean language Northern Pame have been found to more reliably produce noun-class prefixes (including low-frequency ones) when part of a disyllabic foot (Pye et al., 2020).

The Sesotho findings generalise to Romance languages as well, where articles also prosodify to the lexical item to the left. Thus, very similar findings are found in Italian (Giusti & Gozzi, 2006), French (Demuth & Tremblay, 2008; Giusti & Gozzi, 2006) and Spanish (Demuth et al., 2012). This suggests that, once the prosodic structure of the language is determined, one can predict when (in which prosodic contexts) a child will be most likely to produce or omit an article.

Of course, languages also differ in terms of the average number of syllables per word in child-directed speech. For example, English has mostly monosyllabic lexical items, whereas Spanish has mostly di- and trisyllabic words, and even quadrisyllabic words are not uncommon (e.g. *escalera* 'stairs') (Roarke & Demuth, 2000). This means that children learning Romance languages have to be able to produce many more syllables per prosodic word much earlier than their English-speaking peers. Note that, although English does have some trisyllabic words, there are not many, and these are typically truncated until the age of 3 – e.g. *banana* > nana, *elephant* > efant (e.g. Demuth, 1996; Kehoe & Stoel-Gammon, 1997). Similar patterns are found in Dutch (e.g. Fikkert, 1994) and Spanish (e.g. Gennari & Demuth, 1997).

It is therefore interesting to find that children learning Spanish, for example, begin producing much longer words earlier than their English-speaking peers. Although some words are truncated early on (e.g. *muñeca* > meca 'doll'), these shortened forms also begin to be used with an article (*la+meca* for *la+muñeca*) before the age of 2 (see Demuth et al., 2012; Gennari & Demuth, 1997). This suggests that children learning languages like Spanish and Italian, which have longer lexical items with more syllables, have larger, more complex prosodic word structures earlier than their English-speaking peers, where most of the high-frequency lexical items are monosyllables. Thus, children learning Spanish can accommodate articles that fall outside the domain of the foot much earlier than their English-speaking peers. This suggests that aspects of the ambient lexicon influence the growth of prosodic structure, and hence the rate at which articles appear in children's early speech – all else being equal.

Individual Variation

Of course – even for a given language, all else may not be equal, giving rise to individual variation. Recall from above, we noted that prosodic constraints on the appearance of grammatical function items assume the syntax and semantics are all in place. In the longitudinal study of two Spanish-speaking children, Demuth et al. (2012) noted that one child (a girl) robustly demonstrated the patterns described above, quickly using articles even with truncated lexical items. However, the other child (a boy) was much later at using articles, and when he finally did, he had stopped truncating lexical items. This suggests either that he did not want to use articles if it meant the truncation of the lexical form (maintaining 'lexical integrity' [cf. Spencer, 1991]) or, most likely, that he was slower in acquiring the syntax and semantics needed to use articles. We suspect that the answer is the latter. A similar pattern was also noted in a sample of six children from the Providence Corpus (English), where one of the boys, who had lower overall lexical development (as measured by the MacArthur Communicative Development Inventory [MCDI]; Fenson et al., 2000), used very few articles in any prosodic context. Again, here, we suggest that he was late in acquiring the syntactic and semantic knowledge needed to use articles. Thus, given the prosodic expectations outlined above, it is then easier to identify those children who may be delayed in general language development.

Another source of individual variation found in the Providence Corpus was that one of the girls (Lily) had many more unfooted articles than expected – unlike the other children (Demuth & McCullough, 2009). Acoustic analysis revealed that she was 'stressing' her articles at 1;10, producing them as independent prosodic words. This was surprising, since articles are typically unstressed. By 2;0 however, she had begun to produce articles as unstressed forms, letting them prosodically cliticise to the right or left, depending on the prosodic context. It is not yet clear what gives rise to this type of individual variation: more longitudinal studies of the spontaneous speech of children below 2;0, with acoustically clear recordings, are needed to better understand these types of individual variations.

In sum, the findings reported above suggest that, across languages, children are most likely to first produce articles (and other reduced function words) in prosodically licenced contexts (all else being equal), giving rise to the Prosodic Licensing Hypothesis (Demuth, 2014). That is, children's developing prosodic knowledge/competence, the prosodic structure of the grammatical morpheme and the lexicon, and the prosodic context in which the function words appear can account for much of the reported early variable use. In contrast, children who exhibit no use of function words have probably not yet acquired the necessary syntax or semantics. This, then, raises questions about the use of grammatical inflections, which may only be realised as a segment. We turn to the issue of inflectional morphology below, showing that both prosodic and other factors play a role in when and how these are acquired.

Phonological Effects on the Acquisition of Inflectional Morphology

Inflectional morphemes share many phonological similarities with grammatical function words. They occur relatively frequently in everyday speech and are phonologically short. They can consist of an unstressed syllable (e.g. the present participle -ing on *walk**ing*** /wo:k**ɪŋ**/), a single consonant at the end of a word (e.g. the past tense -ed on *walk**ed*** /wo:k**t**/), or nothing at all (e.g. the absence of a plural morpheme on a word such as dog /dɔg_/ does not mean number is not marked; it indicates the word is grammatically singular) (see Corbett, 2000). Just like with function words, children's acquisition of inflectional morphemes is affected by prosodic context in both perception/comprehension and production.

As many parents will attest, children's early use of inflectional morphemes can be inconsistent. A child might produce an utterance such as '*Look! Doggies!*', and then immediately go on to say, '*Those doggy funny!*'. In his study of the spontaneous speech of three children – Adam, Eve and Sarah – Brown (1973) proposed that the benchmark for a child's acquisition of a given morpheme should be 90% use in obligatory contexts. As a result, children were shown to 'acquire' different grammatical morphemes at different stages of development. For example, the plural was acquired earlier than the 3rd person singular (3SG), even though the two morphemes have identical surface forms. However, this raises questions about the status of children's morphological representations. What sort of representation does a child have if a given morpheme is produced 85% of the time, and why are some grammatical morphemes acquired earlier than others?

As noted above, several proposals have been offered to account for young children's variable use of grammatical morphemes, such as developing syntactic abilities (e.g. Wexler, 1994) or immature morphological competence (Marcus et al., 1992). However, a picture is emerging that children's early use of inflectional morphemes is *prosodically licensed* at the level of the word and syllable, in which the phonological makeup of the coda affects the probability of a child producing a given morpheme. For example, 2-year-olds were more likely to produce the 3SG when it occurred as a phonologically simple coda (e.g. *see**s*** /si:**z**/) as opposed to part of a coda cluster (e.g. *walk**s*** /wo:k**s**/; Song et al., 2009). Similar effects have been found for both the possessive (Mealings & Demuth, 2014) and the plural (Theodore et al., 2011). Children have also been found to be more likely to produce the plural morpheme when it occurs within a coda cluster containing a liquid or nasal segment (e.g. *b**alls*** /bo**lz**/) than with a stop (e.g. *dogs* /dɔ**gz**/) (Ettlinger & Zapf, 2011). That is, children were more likely to produce the plural when the segments within the syllable rime have decreasing sonority (the Sonority Sequencing Principle; see Clements, 1990). They are also more likely to produce both plural and 3SG morphemes occurring utterance-finally as opposed to utterance-medially (Song et al., 2009; Theodore et al., 2011).

The effect of utterance position on children's acquisition of inflectional morphemes is two-fold. In English, the prosodic phenomenon of phrase-final lengthening affords children more time for speech planning and articulation in utterance-final syllables. It also means that grammatical morphemes occurring phrase-finally have greater perceptual salience due to their longer duration. In other words, children are more able to perceive and encode phrase-final morphemes from their speech input than morphemes occurring utterance-medially. A study looking at the differences between the plural and 3sg morphemes in child-directed speech demonstrated that, not only was the earlier-acquired plural more frequent in children's input, it was also more likely to appear utterance-finally (Hsieh et al., 1999). Furthermore, perception studies have shown that 22-month-olds demonstrate sensitivity to the presence/absence of 3sg when it occurs utterance finally (e.g. *Now she cri**es***) but not when it occurs utterance-medially (e.g. *She cri**es** now*) (Sundara et al., 2011). Indeed, the emerging picture is that children's early production and perception of grammatical morphemes are both greatly affected by prosodic properties of their language. Yet, discrepancies between children's earliest abilities to perceive inflectional morphemes and their much later abilities to comprehend them suggest that children's initial representations of some grammatical morphemes may be simply phonological.

Perceptual Representation of Morphemes

Studies measuring young children's looking behaviour show that children acquiring English are sensitive to the grammatical presence/absence of 3sg from as young as 16 months (Soderstrom et al., 2007; Sundara et al., 2011). Studies of children's spontaneous speech show that children reach the 90% production benchmark sometime after the age of 3 (Brown, 1973; De Villiers & De Villiers, 1973). Yet studies employing picture-pointing tasks find that children still struggle to demonstrate comprehension of 3sg even after the age of 6 (De Villiers & Johnson, 2007; Johnson et al., 2005). While this particular morpheme may be more difficult than others as it requires some level of understanding of subject-verb agreement (a higher-level syntactic process), the difference in age from when children are first sensitive to 3sg to when they are first able to demonstrate comprehension is striking.

One potential reason for this discrepancy could lie in the methodological differences between these studies. Infant studies predominantly focus on perception, whereas studies with older children require semantic interpretation, which is inherently more difficult (Naigles, 2002). However, perception studies show that young children have expectations about the distributional probabilities of the phonological structures in their language (e.g. Baer-Henney et al., 2015). This is argued to extend to their sensitivity to the presence/absence of inflectional morphemes as well; they may not know exactly what 3sg is, or what it does, but they are sensitive to when it is missing from an utterance (Soderstrom, 2008). This may suggest that, just as an infant's earliest lexical representations are extracted from the speech stream through the early representation of prosodic words (Cutler & Norris, 1988), children may acquire initial *perceptual* representations of grammatical morphemes through distributional cues in the prosodic/phonological structure of the language input they hear.

The Acquisition of Allomorphic Variants

Allomorphic variation adds another layer of complexity to children's acquisition of inflectional morphology. In English, for example, the surface forms of many grammatical morphemes change, depending on the phonological properties of the words onto which they attach. Words such as *cats, dogs* and *busses* are all inflected with the plural morpheme, yet each word employs a different surface form, or allomorph, of the plural. Knowing which allomorph attaches to which word requires an understanding of morpho-phonological processes. In this case, the syllabic plural allomorph /-**ə**z/ attaches to sibilants, as is *busses* /b**ɐ**ss+**ə**z/ and *roses* /**ɹəʉ**z+**ə**z/; the voiceless segmental plural allomorph /s/ attaches to voiceless consonants such as in *cats* /$\mathrm{k^h}$æts/ and *socks* /s**ɔ**ks/; while the voiced segmental allomorph /z/ follows vowels and voiced consonants, such as in *dogs* /d**ɔ**gz/ or *zoos* /zu:z/. Similar processes occur in Spanish, where the segmental plural morpheme /-s/ attaches to vowels (e.g. *gatos* /gato**s**/ 'cats') and the syllabic plural morpheme /-es/ attaches to consonants (e.g. *panes* /pan**es**/ 'breads'). In languages such as Dutch, several morpho-phonological processes are in play. The two regular plural allomorphs, /-s/ and /-**ə**n/, tend to attach to nominal stems, depending on the stress properties of the final syllable and the sonority properties of the coda consonant.

Production studies employing novel items can reveal children's knowledge of allomorphic variation. For example, using *wug* tasks (Berko, 1958), children are presented with prompts such as '*This is a wug. Now there are two of them. There are two…?*' in order to elicit a plural form – in this case: '*wugs*'. These studies typically use novel words (i.e. made-up words that are unfamiliar to the children in the study) to ensure that children are being tested on their understanding of the plural morpheme, and not on known plural forms they may have memorised as whole words. Thus, the only way to know that the plural of *wug* is *wugs* is by applying productive knowledge of the plural morphology (i.e. *wug+s*).

In Berko's (1958) classic study, 4- to 7-year-olds were able to produce novel words such as *wugs* and *luns* appropriately roughly 90% of the time. However, words with the syllabic plural /-**ə**z/, such as *tasses* and *nizzes*, were produced correctly only around 30% of the time. Other *wug* studies have found similar results (Graves & Koziol, 1971; Matthews & Theakston, 2006). Berko (1958) suggested that this might be due to children interpreting words ending in fricatives as already inflected for plural. However, English is not the only language in which allomorphic variation affects children's production. In *wug* studies carried out in Spanish, 3- to 6-year-olds had greater difficulty inflecting words with the Spanish syllabic plural /-es/ than they did with the segmental plural /-s/ (Arias-Trejo, Abreu-Mendoza et al., 2014). In Palestinian Arabic, children were found to be using the feminine plural allomorph /a:t/ appropriately from around age 3 but continued to have difficulty with the masculine plural /u:n/ and the phonologically complex broken plural until well past age 6 (Ravid & Farah, 1999; Saiegh-Haddad et al., 2012).

Input frequency offers one explanation as to why children are better at producing some allomorphs than others. In English, the later-acquired syllabic plural /-**ə**z/ allomorph accounts for only 6% of the plurals children hear in their input (Davies et al., 2017). Similarly, in Spanish only approximately 13% of the nouns children hear use the later-acquired syllabic plural /-es/ allomorph (Jackson-Maldonado, 2003, as reported in Arias-Trejo, Cantrell et al., 2014). In Palestinian Arabic, the earliest-acquired allomorph, the feminine plural /a:t/, is also the most frequent (Saiegh-Haddad et al., 2012). In a study of children's acquisition of German plural markings, Szagun (2001) showed a close relationship between children's emerging proficiency with each German plural allomorph and its frequency in child-directed speech. However, while input frequency likely plays an important role, studies of children's emerging *comprehension* of plural morphology show that perceptual salience is also important.

Studies are increasingly employing novel-word paradigms and measuring children's eye movements to examine *comprehension* of the plural morpheme. For example, Kouider et al. (2006) presented children with two pictures: one of a single novel object (the singular target) and the other of multiple novel objects (the plural target). Children were told to '*Look at the blicket*' or '*Look at the blickets*'. In that study, 3-year-olds successfully looked at the singular target when presented with a singular novel word and the plural target when presented with a plural novel word. However, 2-year-olds' looking behaviour appeared to be at chance. That is, despite producing plurals in their everyday speech (Brown, 1973; De Villiers & De Villiers, 1973), 2-year-olds did not appear to *comprehend* plural morphology. Conversely, using the same paradigm, Arias-Trejo, Cantrell et al. (2014) showed that Mexican Spanish-speaking 2-year-olds were able to comprehend novel plural nouns. Aside from the language tested, the two studies differed in one important way: Kouider et al. (2006) tested children on a combination of all three English plural allomorphs, /-s/, /-z/ and /-əz/, whereas Arias-Trejo, Cantrell et al. (2014) tested only the earlier produced Spanish plural allomorph /-s/.

When allomorphic variation was controlled, Davies et al. (2017) found that English-speaking 2-year-olds could demonstrate comprehension of the voiceless segmental plural allomorph /-s/ but not of the voiced allomorph /-z/. If frequency were the only factor guiding children's acquisition of allomorphs, we should expect the opposite, as the voiced segmental plural allomorph /-z/ is roughly three times more frequent in children's input than its voiceless counterpart /-s/ by both type and token (Davies et al., 2017). However, acoustically the plural allomorph /-s/ is significantly longer in duration than /-z/, suggesting that the perceptual salience of a morpheme/allomorph in children's input plays an important role in predicting when it will be learnt. Yet, perceptual salience alone is not enough; children do not demonstrate comprehension of the most perceptually salient syllabic plural /-əz/ until the age of 3 (Davies et al., 2020; Kouider et al., 2006). It appears that children's acquisition is guided by an interaction between frequency and perceptual salience. Indeed, if children's initial *perceptual* representations of morphemes/allomorphs are acquired through paying attention to the distributional cues in their input (as suggested by Soderstrom, 2008), these need to be frequent enough for children to notice a pattern and perceptually salient enough for children to notice at all.

The *singular* offers an interesting insight into the roles of frequency and perceptual salience in acquisition. In English, the singular is marked through the absence of the plural; *dog* is singular precisely because it does not have a plural morpheme attached. Because of this, the singular is often regarded as a 'null' morpheme. (However, note that this is not universal; Bantu languages such as Sesotho mark both singular and plural with a grammatical morpheme [e.g. *mo-sadi* 'woman', *ba-sadi* 'women']). Given that the singular is generally highly frequent but realised as null in English, perhaps we should expect children to have difficulty with its acquisition. However, the evidence is mixed; *wug* tasks reveal little difference between young children's ability to inflect novel singulars into plurals and their ability to transform plurals into singulars (Zapf & Smith, 2007). In contrast, while children demonstrate comprehension of plural allomorph /-s/ at 24 months, they show no comprehension of the singular (Davies et al., 2017). (Interestingly, this is also true for Spanish, which also has a null singular morpheme; Arias-Trejo, Cantrell et al., 2014). By the age of 3, children demonstrate comprehension of all plural allomorphs, including the singular (Davies et al., 2020; Kouider et al., 2006). However, in a task in which 3- to 5-year-olds had to explicitly demonstrate comprehension of the singular and plural of novel words by touching the correct picture on an iPad, they became better at identifying plurals with age but did not get better at identifying singulars (Davies et al., 2019). This suggests that singular and plural morphemes are on separate developmental trajectories, with the singular being the more difficult of the two, at least in a language like English. It would be very interesting to follow up with studies of, for example, a Bantu language, where both singular and plural are morphologically marked, to see whether children then acquire both singular and plural morphology at the same time in both comprehension and production.

Conclusion

In sum, this chapter has reviewed some of the literature demonstrating how children's developing competences with phonology/prosody play an important role in their developing representations of morphosyntax. In production, children's use of grammatical function words and inflectional morphemes are prosodically licenced, first at the level of the prosodic word and syllable, and then at higher levels of the phonological phrase and the intonation phrase. In comprehension, phonological/prosodic characteristics of input (e.g. phrase-final lengthening) affect when and how children acquire inflectional morphemes. Understanding the mechanisms underlying children's early phonological and morphological development is not just theoretically important but also has implications for those taking different paths towards acquiring language, such as children with hearing loss or Developmental Language Disorder (DLD).

References

Arias-Trejo, N., Abreu-Mendoza, R. A. & Aguado-Servín, O. A. (2014). Spanish-speaking children's production of number morphology. *First Language*, 34(4), 372–384. doi:10.1177/0142723714544411.

Arias-Trejo, N., Cantrell, L. M., Smith, L. B., & Canto, E. A. A. (2014). Early comprehension of the Spanish plural. *Journal of Child Language*, 41(6), 1356–1372. doi:10.1017/S0305000913000615.

Baer-Henney, D., Kügler, F., & van de Vijver, R. (2015). The interaction of language-specific and universal factors during the acquisition of morphophonemic alternations with exceptions. *Cognitive Science*, 39(7), 1537–1569. doi:10.1111/cogs.12209.

Berko, J. (1958). The child's learning of English morphology. *Word*, 14(2–3), 150–177. doi:10.1080/00437956.1958.11659661.

Brown, R. (1973). *A first language: The early stages*. Cambridge, MA: Harvard University Press.

Clements, G. N. (1990). The role of the sonority cycle in core syllabification. In J. Kingston & M. E. Beckman (Eds.), *Papers in laboratory phonology: Volume 1, Between the grammar and physics of speech* (pp. 283–333). Cambridge: Cambridge University Press.

Corbett, G. G. (2000). *Number*. Cambridge: Cambridge University Press.

Cutler, A., & Norris, D. (1988). The role of strong syllables in segmentation for lexical access. *Journal of Experimental Psychology: Human Perception and Performance*, 14(1), 113–121. doi:10.1037/0096-1523.14.1.113.

Davies, B., Xu Rattanasone, N. & Demuth, K. (2017). Two-year-olds' sensitivity to inflectional plural morphology: Allomorphic effects. *Language Learning and Development*, 13(1), 38–53. doi:10.1080/15475441.2016.1219257.

Davies, B., Xu Rattanasone, N. & Demuth, K. (2020). Acquiring the last plural: Morphophonological effects on the comprehension of /-əz/. *Language Learning and Development*, 16(2), 161–179. doi:10.1080/15475441.2020.1717956.

Davies, B., Xu Rattanasone, N., Schembri, T. & Demuth, K. (2019). Preschoolers' developing comprehension of the plural: The effects of number and allomorphic variation. *Journal of Experimental Child Psychology*, 185, 95–108. doi:10.1016/j.jecp.2019.04.015.

De Villiers, J. G., & de Villiers, P. A. (1973). A cross-sectional study of the acquisition of grammatical morphemes in child speech. *Journal of Psycholinguistic Research*, 2(3), 267–278. doi:10.1007/BF01067106.

De Villiers, J. G., & Johnson, V. E. (2007). The information in third-person /s/: Acquisition across dialects of American English. *Journal of Child Language*, 34(1), 133–158. doi:10.1017/S0305000906007768.

Demuth, K. (1992). Accessing functional categories in Sesotho: Interactions at the morpho-syntax interface. In J. M. Meisel (Ed.), *The acquisition of verb placement: Functional categories and V2 phenomena in language acquisition* (pp. 83–107). Dordrecht: Springer Netherlands.

Demuth, K. (1996). The prosodic structure of early words. In J. L. Morgan & K. Demuth (Eds.), *Signal to syntax: Bootstrapping from speech to grammar in early acquisition* (pp. 171–184). Mahwah, NJ: Lawrence Erlbaum Associates.

Demuth, K. (2014). Prosodic licensing and the development of phonological and morphological representations. In A. W. Farris-Trimble and J. A. Barlow (Eds.), *Perspectives on phonological theory and development in honor of Daniel A. Dinnsen* (pp. 11–24). Amsterdam: John Benjamins.

Demuth, K., & Ellis, D. (2009). Revisiting the acquisition of Sesotho noun class prefixes. In *Crosslinguistic approaches to the psychology of language: Research in the tradition of Dan Isaac Slobin* (pp. 93–104). New York: Psychology Press.

Demuth, K., & McCullough, E. (2009). The prosodic (re)organization of children's early English articles★. *Journal of Child Language*, 36(1), 173–200. doi:10.1017/S0305000908008921.

Demuth, K., Patrolia, M., Song, J. Y., & Masapollo, M. (2012). The development of articles in children's early Spanish: Prosodic interactions between lexical and grammatical form. *First Language*, 32(1–2), 17–37. doi:10.1177/0142723710396796.

Demuth, K., & Tremblay, A. (2008). Prosodically-conditioned variability in children's production of French determiners. *Journal of Child Language*, 35(1), 99–127. doi:10.1017/S0305000907008276.

Ettlinger, M., & Zapf, J. (2011). The role of phonology in children's acquisition of the plural. *Language Acquisition*, 18(4), 294–313. doi:10.1080/10489223.2011.605044.

Fenson, L., Pethick, S., Renda, C., Cox, J. L., Dale, P. S. & Reznick, J. S. (2000). Short-form versions of the MacArthur communicative development inventories. *Applied Psycholinguistics*, 21(1), 95–116. https://mb-cdi.stanford.edu/documents/Fensonetal2000.pdf.

Fikkert, J. P. M. (1994). *On the acquisition of prosodic structure*. Leiden: J.P.M. Fikkert.

Gennari, S., & Demuth, K. (1997). Syllable omission in the acquisition of Spanish. In E. Hughes, M. Hughes & A. Greenhill (Eds.), *Proceedings of the Annual Boston University Conference on Language Development*, Vol. 1. (pp. 182–193). Medford, MA: Cascadilla Press.

Gerken, L. (1996). Prosodic structure in young children's language production. *Language*, 72(4), 683–712. doi:10.2307/416099.

Gerken, L., & McIntosh, B. J. (1993). Interplay of function morphemes and prosody in early language. *Developmental Psychology*, 29(3), 448–457. doi:10.1037/0012-1649.29.3.448.

Giusti, G., & Gozzi, R. (2006). The acquisition of determiners: Evidence for the full competence hypothesis. In A. Belletti, E. Bennati, C. Chesi, E. Di Domenico, & I. Ferrari (Eds.), *Language acquisition and development: Proceedings of GALA 2005* (pp. 232–238). Newcastle: Cambridge Scholars Publishing.

Graves, M. F., & Koziol, S. (1971). Noun plural development in primary grade children. *Child Development*, 42(4), 1165–1173. doi:10.2307/1127801.

Hsieh, L., Leonard, L. B., & Swanson, L. (1999). Some differences between English plural noun inflections and third singular verb inflections in the input: The contributions of frequency, sentence position, and duration. *Journal of Child Language*, 26(3), 531–543. doi:10.1017/S030500099900392X.

Hyams, N. (2007). Aspectual effects on interpretation in early grammar. *Language Acquisition*, 14(3), 231–268. doi:10.1080/10489220701470992.

Jackson-Maldonado, D. (Ed.). (2003). *MacArthur Inventarios del Desarrollo de Habilidades Comunicativas: User's guide and technical manual*. Baltimore: P.H. Brookes.

Johnson, V. E., de Villiers, J. G., & Seymour, H. N. (2005). Agreement without understanding? The case of third person singular /s/. *First Language*, 25(3), 317–330. doi:10.1177/0142723705053120.

Jusczyk, P. W. (1997). Finding and remembering words: Some beginnings by English-learning infants. *Current Directions in Psychological Science*, 6(6), 170–174. doi:10.1111/1467-8721.ep10772947.

Kehoe, M., & Stoel-Gammon, C. (1997). Truncation patterns in English-speaking children's word productions. *Journal of Speech, Language, and Hearing Research*, 40(3), 526–541. doi:10.1044/jslhr.4003.526.

Kouider, S., Halberda, J., Wood, J. & Carey, S. (2006). Acquisition of English number marking: The singular-plural distinction. *Language Learning and Development*, 2(1), 1–25. doi:10.1207/s15473341lld0201_1.

Kuhl, P. K. (2004). Early language acquisition: Cracking the speech code. *Nature Reviews Neuroscience*, 5(11), 831–843. doi:10.1038/nrn1533.

Marcus, G. F., Pinker, S., Ullman, M., Hollander, M., Rosen, T. J., Xu, F. & Clahsen, H. (1992). Overregularization in language acquisition. *Monographs of the Society for Research in Child Development*, 57(4), i–178. doi:10.2307/1166115.

Matthews, D. E., & Theakston, A. L. (2006). Errors of omission in English-speaking children's production of plurals and the past tense: The effects of frequency, phonology, and competition. *Cognitive Science*, 30(6), 1027–1052. doi:10.1207/s15516709cog0000_66.

Mattys, S. L., Jusczyk, P. W., Luce, P. A. & Morgan, J. L. (1999). Phonotactic and prosodic effects on word segmentation in infants. *Cognitive Psychology*, 38(4), 465–494. doi:10.1006/cogp.1999.0721.

Mealings, K. T., & Demuth, K. (2014). Cluster reduction and compensatory lengthening in the acquisition of possessive -s. *Journal of Child Language*, 41(3), 690–704. doi:10.1017/S0305000913000093.

Naigles, L. (2002). Form is easy, meaning is hard: Resolving a paradox in early child language. *Cognition*, 86(2), 157–199. doi:10.1016/S0010-0277(02)00177–00174.

Nespor, M., & Vogel, I. (1986). *Prosodic phonology*. Dordercht: Foris.

Peters, A. M. (1983). *The units of language acquisition*. Cambridge: Cambridge University Press.

Pye, C., Berthiaume, S. & Pfeiler, B. (2020). The acquisition of noun inflection in Northern Pame (Xi'iuy): Comparing whole word and minimal word accounts. *Journal of Child Language*, 48(6): 1067–1100. doi:10.1017/S0305000920000586.

Radford, A. (1990). *Syntactic theory and the acquisition of English syntax: The nature of early child grammars of English*. Oxford: Blackwell.

Ramus, F., Nespor, M., & Mehler, J. (1999). Correlates of linguistic rhythm in the speech signal. *Cognition*, 73(3), 265–292. doi:10.1016/S0010-0277(99)00058-X.

Ravid, D., & Farah, R. (1999). Learning about noun plurals in early Palestinian Arabic. *First Language*, 19(56), 187–206. doi:10.1177/014272379901905603.

Roarke, B., & Demuth, K. (2000). Prosodic constraints and the learner's environment: A corpus study. In S. C. Howell, S. A. Fish, & T. Keith-Lucas (Eds.), *Proceedings of the 24th Annual Boston University Conference on Language Development* (pp. 597–608). Medford, MA: Cascadilla Press.

Saiegh-Haddad, E., Hadieh, A. & Ravid, D. (2012). Acquiring noun plurals in Palestinian Arabic: Morphology, familiarity, and pattern frequency. *Language Learning*, 62(4), 1079–1109. doi:10.1111/j.1467-9922.2012.00727.x.

Selkirk, E. (1984). *Phonology and syntax: The relation between sound and structure*. Cambridge, MA: MIT Press.

Selkirk, E. (1996). In the prosodic structure of function words. In J. L. Morgan & K. Demuth (Eds.), *Signal to syntax: Bootstrapping from speech to grammar in early acquisition* (pp. 187–213). Hillsdale, NJ: Lawrence Erlbaum Associates.

Shi, R., & Gauthier, B. (2005). Recognition of function words in 8-month-old French-learning infants. *The Journal of the Acoustical Society of America*, 117(4), 2426–2427. doi:10.1121/1.4786583.

Soderstrom, M. (2008). Early perception–late comprehension of grammar? The case of verbal -s: A response to de Villiers & Johnson (2007). *Journal of Child Language*, 35(3), 671–676. doi:10.1017/S0305000907008616.

Soderstrom, M., White, K. S., Conwell, E. & Morgan, J. L. (2007). Receptive grammatical knowledge of familiar content words and inflection in 16-month-olds. *Infancy*, 12(1), 1–29. doi:10.1111/j.1532-7078.2007.tb00231.x.

Song, J. Y., Sundara, M. & Demuth, K. (2009). Phonological constraints on children's production of English third person singular –s. *Journal of Speech, Language, and Hearing Research*, 52(3), 623–642. doi:10.1044/1092-4388(2008/07–0258).

Spencer, A. (1991). *Morphological theory: An introduction to word structure in Generative grammar*. Oxford: Basil Blackwell.

Sundara, M., Demuth, K. & Kuhl, P. K. (2011). Sentence-position effects on children's perception and production of English third person singular –s. *Journal of Speech Language and Hearing Research*, 54(1), 55–71. doi:10.1044/1092-4388(2010/10–0056).

Szagun, G. (2001). Learning different regularities: The acquisition of noun plurals by German-speaking children. *First Language*, 21(62), 109–141. doi:10.1177/014272370102106201.

Theodore, R. M., Demuth, K., & Shattuck-Hufnagel, S. (2011). Acoustic evidence for positional and complexity effects on children's production of plural –s. *Journal of Speech, Language, and Hearing Research*, 54(2), 539–548. doi:10.1044/1092-4388(2010/10–0035).

Veneziano, E., & Sinclair, H. (2000). The changing status of 'filler syllables' on the way to grammatical morphemes. *Journal of Child Language*, 27(3), 461–500. doi:10.1017/s030500090000427x.

Wexler, K. (1994). Finiteness and head movement in early child grammars. In D. Lightfoot & N. Hornstein (Eds.), *Verb movement* (pp. 305–350). Cambridge: Cambridge University Press.

Zapf, J. A., & Smith, L. B. (2007). When do children generalize the plural to novel nouns? *First Language*, 27(1), 53–73. doi:10.1177/0142723707070286.

Zipf, G. K. (1932). *Selected studies of the principle of relative frequency in language*. Cambridge, MA: Harvard University Press.

14

THE ROLE OF MORPHOLOGY IN READING DEVELOPMENT

Jana Hasenäcker, Petroula Mousikou and Sascha Schroeder

Introduction

Learning to read is an important milestone for individuals in a literate society. Not only is it necessary in everyday life, but it also facilitates access to resources of knowledge. The first ability that needs to be acquired when learning to read—at least in alphabetic orthographies—is translating letters into sounds. Children draw on their knowledge from spoken language to map print onto phonological representations. Accordingly, most research has focused on the role of phonology in reading development. However, children also need to learn to map print onto meaning in order to recognize words quickly, reliably, and efficiently (Nation, 2009). This can be supported by morphology, which enables children to make connections between form and meaning.

Morphology has recently attracted increased attention in developmental reading research (Rastle, 2018). An important feature of morphology is that it provides an "island of regularity" (Rastle et al., 2000), in contrast to the otherwise arbitrary mapping between form and meaning. For instance, the meaning of the word *read* cannot be deduced from its visual or auditory form, but *readable* is systematically related to its parts *read* and *-able*, keeping both form and meaning constant. Critically, children encounter a significant number of morphologically complex words during their first years in school (Anglin, 1993; Segbers & Schroeder, 2017). Hence, it is important to determine how morphology is used during the process of learning to read.

It is generally thought that children use morphology during reading development in two ways: (1) by drawing on their stored knowledge of morphological structure from spoken language; and (2) by exploiting morphological structure in an online manner. Some of the specific questions that have been recently addressed are: How does morphological knowledge from spoken language support reading acquisition?

DOI: 10.4324/9781003159759-14

Which aspects of reading ability (i.e., accuracy, speed, comprehension) are influenced by morphological knowledge? How are morphologically complex words recognized during reading? How is morphological processing developed over time, and does it differ across languages or individuals? How can morphology be used in instruction or intervention studies to facilitate reading acquisition?

The purpose of this chapter is to provide an overview of the current state of research on the role of morphology in reading development. The chapter focuses primarily on word formation in morphology, that is, derivations and, to a lesser extent, compounding. Even though inflectional morphology is thought to play an important role in the development of spoken language and meta-linguistic awareness (cf. Davies & Demuth, this volume), little is known about its influence on reading mechanisms during development. The chapter begins by describing the most common methodological approaches used in empirical studies on morphology in reading development, and we report their main findings. In the following section, we outline how morphology is conceptualized in models of reading development. We then consider inter-individual and cross-linguistic differences in morphological processing, before moving on to discuss morphological training in reading across the lifespan. We conclude with potential challenges for future research.

Methodological Issues

Both meta-linguistic and online tasks have been used to investigate morphological processing in reading development. While the former type of task measures morphological knowledge and individuals' ability to manipulate morphological structure explicitly, the latter type of task measures sensitivity to morphological structure during stimulus processing, often tapping into subliminal reading mechanisms. However, the distinction between the two types of tasks is not always clear-cut, and the processes that they tap into are interdependent. Below, we describe the most common tasks used in the literature, and report their empirical findings.

Meta-Linguistic Tasks

A number of tasks have been used to test children's morphological awareness, that is, the ability to consciously analyze morphological structure and manipulate morphemes (Apel, 2014; Carlisle, 1995, 2000). Most of the tasks were designed for pre-literate children, and there is striking diversity in the tasks used, with different tasks measuring different aspects of morphological awareness (Apel et al., 2013). Moreover, morphological awareness is often classified into morphological structure awareness and morphological analysis (Levesque et al., 2019). The former refers to children's knowledge about morphological structure in their language, whereas the latter refers to the use of this structure to resolve word meaning. These aspects are clearly related but might serve different purposes in reading development. They therefore need to be investigated separately.

The prototypical morphological structure awareness task is Berko's (1958) "wug" test. Children are introduced to novel names of entities accompanied by pictures ("This is a *wug*.") and then asked to complete sentences using the nonce words ("Now there are two of them. There are two …"). This task requires children to draw on their morphological knowledge to produce different inflectional forms (e.g., plural, past tense, comparative, possessive), as well as compounds. Since Berko's seminal study, many morphological awareness tests have used similar sentence completion tasks also with derivations (Carlisle, 1995, 2000; McCutchen et al., 2008). Hinging on the same principle are tasks where children have to produce a form based on analogy (Kirby et al., 2012; Nunes et al., 1997). Studies on morphological structure awareness have shown that children acquire meta-linguistic knowledge of morphological principles and can manipulate morphemes already at pre-school age, while they continue to develop this ability throughout elementary school (Carlisle, 2000; Casalis & Louis-Alexandre, 2000).

Morphological analysis tasks reflect the use of morphemic structure to determine the meaning of complex words, as well as the relationship between morphologically related words. Using a definition task, Anglin (1993) showed that 5th-grade children were better at defining derived than monomorphemic words, with half of the produced definitions using references to their stems. These findings suggest that elementary school children make active use of morphemes to understand and explain meaning (Krott & Nicoladis, 2005; McCutchen & Logan, 2011). Also, judgment tasks, explicitly asking participants whether two words are morphologically related or not, reflect the ability to access word meanings to determine morphological relatedness (Carlisle, 1995; Mahony et al., 2000).

Morphological structure awareness and morphological analysis tasks have been found to predict different reading skills. Morphological structure awareness has been most successful in explaining unique variance over and above phonological awareness and vocabulary knowledge in word and pseudoword reading, and also in predicting gains in morphological analysis, which in turn explains reading comprehension (Deacon et al., 2014; Kirby et al., 2012; Levesque et al., 2019). Critically, there is consensus that the relationship between morphological awareness and reading is reciprocal (Kuo & Anderson, 2006; Nunes et al., 1997).

Online Processing Tasks

To investigate whether morphemes are functional units in reading development, a variety of online processing tasks have been used. In these tasks, the experimental items usually consist of monomorphemic and multimorphemic letter strings, and the influence of morphological structure on reading latency and accuracy is measured. Faster and more accurate reading of multimorphemic compared to monomorphemic items, which are otherwise matched on psycholinguistic variables such as frequency, length, etc., is taken as evidence that morphology facilitates reading.

In a seminal study, Carlisle and Fleming (2003) asked English-speaking children to read aloud lists of words ending in *-y*. Those words were either monomorphemic (e.g., *silly*) or multimorphemic (e.g., *hilly*). Multimorphemic words were read faster and more accurately than monomorphemic ones. Similarly, reading aloud studies with Italian children in grades 2 and 3 found increased speed and accuracy for suffixed words (Burani et al., 2008). Subsequent studies have revealed that frequency, length, and grammatical class of the stem can modulate reading times and accuracy in young readers (Burani et al., 2018; Deacon et al., 2011; Marcolini et al., 2011). These studies suggest that the presence of morphemes in printed letter strings is helpful for beginning readers.

Morphologically complex pseudowords present an interesting test case because they resemble unknown multimorphemic words, in the sense that readers are not familiar with them when they first encounter them in print. These items typically consist of a real stem and a real suffix in a new combination (e.g., *film+er*), a real stem and a letter sequence that does not correspond to a suffix (e.g., *film+ap*), a pseudostem and a real suffix (e.g., *folm+er*), or a pseudostem and a non-morphemic letter sequence (e.g., *folm+ap*). Reading aloud studies with developing readers in several Indo-European languages have shown faster and more accurate reading when pseudowords included real morphemes (e.g., Angelelli et al., 2014; Burani et al., 2002; Mousikou et al. 2020). Stems, in particular, are thought to play a special role in reading, as they provide a head start to efficient pseudoword reading (Colé et al., 2012; Traficante et al., 2011).

Accordingly, in lexical decision tasks, where participants are asked to decide whether an item is a real word or a non-word, pseudowords containing real morphemes tend to yield longer and/or less accurate responses than pseudowords with no morphological units. This is because morphologically structured pseudowords look more "word-like" and therefore are harder to respond to as "non-words." Lexical decision studies typically show that the presence of morphemes facilitates word recognition but inhibits pseudoword rejection (e.g., Burani et al., 2002; Dawson et al., 2018; Quémart et al., 2012).

Most lexical decision studies have used suffixed items; prefixed items and compounds have been investigated to a lesser extent. More recently, a cross-sectional study with German children attending grades 2 to 6 compared all three types of multimorphemic items (Hasenäcker et al., 2017). Morphological effects were observed in all grades, first arising for compounds (grade 2), then for suffixed items (grade 3), and last for prefixed items (grade 4). The authors attributed this pattern to two factors: (1) salience of the initial part of the word due to a left-to-right processing bias in beginning readers; and (2) salience of stem morphemes, as they carry concrete meaning and correspond to lexical entities (see Grainger & Beyersmann, 2017). These factors might lead to earlier decomposition of compounds, composed of two stems, then suffixed items, containing the stem word-initially, and lastly prefixed items, containing the stem word-finally. Studies manipulating compound frequency in terms of the whole compound and its constituent stems (De Zeeuw et al., 2015; Hasenäcker & Schroeder, 2017) also affirm children's sensitivity to stems in word processing.

A paradigm that has been extensively used in lexical decision tasks in this domain is masked priming (Forster & Davis, 1984): a mask (####) is presented first, followed by a briefly presented (~50 ms) prime stimulus, which is then replaced by the target. Even though most participants are unaware of the presence of the prime, it exerts an influence on the response to the target. Lexical decision times are faster when a target word (e.g., *teach*) is preceded by a morphologically related prime (*teacher*), compared to when the prime is morphologically unrelated to the target (e.g., *dancer*). Morphological priming effects have been observed for elementary school children in several languages (e.g., Beyersmann et al., 2012; Quémart et al., 2011). Studies using the masked priming paradigm with skilled adult readers indicate that word recognition is facilitated not only when masked primes are morphologically and semantically related to their targets (e.g., *darkness-DARK*), but also when they have a pseudomorphological relationship (*corner-CORN*, where *corner* is not morphologically related to *corn*, yet consists of an apparent stem and a suffix; Rastle & Davis, 2008). Importantly, such facilitation is not obtained when primes and targets are orthographically but not pseudomorphologically related (*cashew-CASH*, where *ew* is not a suffix). This finding has been taken as evidence for semantically blind morpho-orthographic decomposition into stem and (pseudo)suffix. Critically, similar pseudosuffix effects have been observed in developing readers of French (Quémart et al., 2011), but not of English (Beyersmann et al., 2012). The paradigm has also been adapted to Hebrew, in which consonant patterns correspond to roots (e.g., *G-D-L* "grow") that are combined with vowels (*CaCoC*) to form morphologically complex words (*GaDoL* "big"). Schiff et al. (2012) showed that young readers not only show priming from morphologically related pairs (*haDRaKa-maDRiK* "guidance-guide"), but also from semantically distant pairs like the *corner-corn* type (*miDRaKa-maDRiK* "pavement-guide"). Furthermore, both suffixed (*quickify-quick*) and non-suffixed pseudoword primes (*quickint-quick*) have been shown to yield masked priming effects in developing readers of French (Beyersmann et al., 2015) and German (Hasenäcker et al., 2020), indicating that stems are activated early in development, regardless of the presence of a suffix.

The role of morphemes has been contrasted with the role of syllables by Colé et al. (2011), who presented French words that were syllabically segmented (*ma lade*), morphologically segmented (*mal ade*), or segmented in a way that was neither syllabic nor morphological (*mala de*). Equal reading aloud times were obtained for syllabically and morphologically segmented words, suggesting that both units facilitate word recognition (cf. Hasenäcker & Schroeder, 2017, for German).

Semantic categorization has been used recently to investigate whether semantic activation during visual word recognition might be mediated by morpho-orthographic processing (Hasenäcker et al., 2021). Italian elementary school children were asked to decide whether visually presented words belonged to a given category or not (e.g., *is CARROT a type of food?*). Critically, pseudo-suffixed and non-suffixed items were included (*CORNER, PEACE*), such that some category-incongruent words contained category-congruent stems (*CORN, PEA* for category *food*). Both pseudo-suffixed and non-suffixed words with category-congruent stems took longer to reject, while pseudo-suffixed items also elicited more errors. This suggests that orthographic stems are activated regardless of morphological structure, and that activation is fed forward to the semantic level, where a decision-making process strategically uses morphological surface structure. This study thus provides a link between implicit morphological processing and meta-linguistic morphological analysis.

Overall, there is convincing evidence that morphemes play an important role in the online processing of written words, not necessarily from the very beginning, but rather early on in reading acquisition. Their use changes and is refined over the course of development.

Morphology in Models of Reading Development

Despite the growing body of empirical evidence, morphology is not well specified in theoretical models of reading development. This is likely due to the multidimensional nature of morphological knowledge and the distinct ways in which it can impact learning to read. Theories of reading usually focus either on meta-linguistic morphological knowledge as a precursor skill of reading ability, or on the role of morphemes in the word-recognition process. Those aspects are rarely integrated into one coherent theory.

Traditional models of reading development posit that readers of alphabetic languages start out by learning grapheme-to-phoneme correspondence rules, and by sounding out words on a letter-by-letter basis (e.g., Frith, 1986). As their decoding skills and experience with written words increase, children tend to use larger units, such as syllables or whole words, to access meaning directly, bypassing phonological decoding. Reading development is thought to depend on the growing connections between orthography, phonology, and meaning (cf. Ehri, 2005; Seidenberg, 2005). According to the *lexical quality hypothesis* (Perfetti, 2007), the quality of an individual's word representations, containing orthographic, phonological, semantic, and syntactic information, is a predictor of their reading ability. Morphological knowledge increases lexical quality, because morphology brings regularity to the mapping between form and meaning. Therefore, the lexical quality hypothesis can explain how morphological awareness might affect reading development. Also, the *phase theory of reading development* (Ehri, 2005, 2014) and the *dual-foundation model* (Seymour, 2005) postulate that morphemes, along with onsets, rimes, and syllables, might be used in the *consolidated alphabetic phase*, once children have solid knowledge of the alphabetic system. In these theories, morphological units influence reading late in development. It is not specified how morphemes are used in processing.

The *word and affix model* (Beyersmann & Grainger, this volume; Grainger & Beyersmann, 2017) provides a detailed account on how morphemes come into use in online word reading. The account distinguishes between two mechanisms: embedded word activation, which develops early, and morpho-orthographic segmentation, which is a later milestone. After an initial phonological decoding stage, beginning readers learn to map letters onto whole word representations in the orthographic lexicon that in turn link to semantic representations. After a while, children begin to also activate stems embedded in complex words through this pathway, even in the absence of semantic relatedness or affixes. This explains the early pronounced effects of stems reported in empirical studies. Feedback from semantics, drawing on knowledge about morpho-semantic relationships from spoken language, enables children to also establish separate affix representations in the orthographic lexicon over time. Finally, after years of reading experience, this permits the acquisition of a morpho-orthographic segmentation mechanism, hence accounting for specific pseudo-suffix effects reported in adult readers (Rastle & Davis, 2008).

The *morphological pathways framework*, recently put forward by Levesque et al. (2021), links morphological awareness as a precursor skill to the processing-oriented perspective on morphemes in written word identification, embracing the multidimensionality of morphology in reading development. In this model, morphological awareness influences word reading via two pathways. One, referred to as "morphological decoding," enables morpheme detection so as to facilitate the online decomposition of complex words. The other pathway enables morphological analysis—that is, deriving the meaning of morphologically complex words. As Levesque et al. (2021) point out, morphological decoding and morphological analysis are key word-level processes and the distinction between them roughly aligns with the distinction between morpho-orthographic and morpho-semantic processing (cf. Hasenäcker et al., 2021). In line with previous empirical evidence (e.g., Levesque et al., 2019), morphological decoding and analysis can be seen as different from but reliant on morphological awareness. Morphology in this framework also has an impact on text-level comprehension directly through morphological awareness and indirectly through morphological analysis. Thus, the morphological pathways framework connects lower word-level to higher text-level processing.

Inter-Individual Differences

The available empirical evidence points to the idea that the developmental trajectory of morphological processing might not only change across age groups or grades, but also differ across individuals. For example, sensitivity to morphological structure in visual word recognition seems to emerge earlier in children with good vocabulary skills (Hasenäcker et al., 2017). Also, poor readers seem to rely more heavily on morphemes in reading aloud, compared to better readers of the same grade (Marcolini et al., 2011). Likewise, differences in morphological processing have been observed between typically developing and dyslexic readers: dyslexic readers, just like younger children with matched reading skills, seem to benefit more from morphological units within words than typically developing, age-matched children (Burani et al., 2008). Moreover, while good readers can process suffixed and non-suffixed masked primes equally well, yielding significant priming effects for both prime types, poor readers are only sensitive to real suffixed primes (Beyersmann et al., 2015; Hasenäcker et al., 2020). This suggests that reading ability modulates stem access independently of morphological structure.

Cross-Linguistic Differences

Despite the strong focus of research on Indo-European languages (especially English), a relationship between morphological awareness and reading development has also been reported in Semitic languages (Arabic: e.g., Tibi & Kirby, 2017; Hebrew: e.g., Levin et al., 1999), as well as in East Asian languages using syllabic or logographic writing systems (Chinese: e.g., Tong et al., 2009; Japanese: e.g., Muroya et al., 2017; Korean: e.g., Cho et al., 2011). Within the investigated alphabet writing systems, the role of morphological awareness is thought to vary with orthographic consistency. Desrochers et al. (2018) compared morphological awareness in English, French, and Greek 2nd graders and found that it uniquely predicted reading comprehension in all three languages. Importantly, morphological awareness predicted reading fluency in both English and French, yet it was a predictor of reading accuracy only in English, which has a less transparent orthography. This supports the view that morphology facilitates reading by increasing the reliability of spelling-to-sound mappings (Rastle, 2018).

Moreover, online morphological processing could be influenced either by a language's morphological complexity or its orthographic consistency. To our knowledge, only three studies have tested directly whether cross-linguistic differences influence morphological processing in developmental reading. In a lexical decision task with English and French children aged 7 to 10 years, Casalis et al. (2015) found that in both languages the presence of morphemes facilitated word recognition but that it inhibited children's ability to reject pseudowords. However, while the reported morphological effects arose in terms of both accuracy and response latencies in French, they only emerged for accuracy in English. Mousikou et al. (2020) compared morphological processing in English, French, German, and Italian, which vary both in their degree of morphological complexity and in their degree of orthographic transparency. Developing (grade 3) and skilled readers were tested on a reading aloud task that included words and pseudowords with a morphological and non-morphological structure. All readers of English showed more robust morphological effects than readers of the other languages, thus offering support for the idea that the orthographic consistency of a language, and not its morphological complexity, influences the extent to which morphology is used during reading. Beyersmann et al. (2021) compared masked priming in French and German children in grades 3 and 4 longitudinally. They found embedded word priming across both languages, while morpho-orthographic effects were evident only in French children. As French orthography is more complex than German orthography, this is additional evidence that a language's orthography influences how morphology comes into use in reading development. Another explanation the authors offer refers to the primary word formation process in each language: the productive compounding system of German might encourage stem processing, while the rich derivational system of French might encourage affix segmentation earlier in development.

Morphological Instruction and Intervention Studies

As morphology seems to play an important role in reading development, morphological training might prove to be helpful for beginning and/or struggling readers. Empirical work in this domain has a long history, yet we will focus on three lines of research: (1) morphological awareness training at pre-school; (2) morphological instruction at the beginning of reading instruction in typically developing readers; and (3) morphological training for poor readers in high school.

Morphological awareness, as the meta-linguistic ability to consciously analyze and manipulate morphological structure (e.g., Carlisle, 1995), can already be measured in pre-school children and is predictive of later reading development (Levesque et al., 2019). Intervention studies systematically train morphological awareness skills in pre-school children to facilitate word decoding at school entrance (e.g., Apel et al., 2013). These interventions are thus functionally similar to phonological awareness training, which is widely used in pre-school education. Training typically consists of small-group sessions, which take place several times per week with older pre-school children (5–6 years). Children are taught to detect derivational and inflectional affixes and are provided with their meanings. Training activities also involve the segmentation and manipulation of aurally presented materials. Results from these intervention studies show that morphological awareness training is particularly helpful for poor readers. However, transfer effects to indicators of children's (later) literacy skills are rather small, and enhanced training effects for at-risk children are rare (e.g., Apel & Diehm, 2014).

Next to the effectiveness of isolated interventions, there is also literature about how much emphasis should be placed on morphology during regular reading instruction in primary school (e.g., Goodwin et al., 2012). At least as far as English is concerned, there is consensus nowadays that systematic phonics is best practice for early reading instruction (Castles et al., 2018). However, given that English is a morphophonemic system that evolved to jointly represent units of meaning (morphemes) and phonology (phonemes), it has been suggested that early reading instruction should be organized around morphology and phonology rather than just phonology (Bowers & Bowers, 2018). Proponents of the latter approach posit that morphological training improves several literacy skills, including decoding, vocabulary, and spelling. Critics of the approach argue that morphological training effects on reading fluency and text comprehension are weak. In addition, effects of morphological training tend to be compared against the absence of training. When they are instead compared against systematic phonics instruction or other forms of training in a classroom setting (e.g., Devonshire et al., 2013), morphological training effects are much smaller (Goodwin & Ahn, 2013). Thus, it is not clear whether morphological training could complement phonics instruction in English, and whether it would be worth introducing morphology early on in reading instruction or only after grapheme–phoneme correspondence rules have been mastered (Castles et al., 2018).

Morphological training programs for poor readers in secondary school aim at increasing the use of academic vocabulary and text comprehension (Gellert et al., 2020). This is especially the case for individuals from low socioeconomic background, or those who learn English as a second language (Crosson et al., 2019). A specific problem for these students is to understand newly introduced concepts when reading textbooks from different classes. The aim of these programs is to "kick-start" the positive feedback loop between vocabulary knowledge and text comprehension via the use of morphology. In particular, students are taught frequently occurring Latin and Greek affixes and roots (*intra-, -nov-, -ion*, etc.), as well as how to infer their meaning during text reading using specific reading strategies (Goodwin, 2016). Overall, such programs seem to be effective in increasing students' academic vocabulary. They also seem to increase text comprehension, although it is not always clear whether comprehension effects are mediated by an increase in vocabulary skills (Crosson et al., 2019).

Taken together, results suggest that teaching morphology can be helpful for developing readers of various age groups and ability levels. This idea is in line with the results of several meta-analyses and review articles supporting the effectiveness of morphological training (e.g., Bowers et al., 2010; Goodwin & Ahn, 2013; Reed, 2008). However, the studies included in most meta-analyses on this topic are very heterogeneous. As a consequence, it is not surprising that outcomes vary considerably across studies (e.g., the effectiveness of morphological training often varies as a function of the specific type of training used, the target population, and the selected outcome measures).

Conclusions and Outlook

The goal of this chapter was to provide an overview of the role of morphology in reading development. The reviewed empirical evidence points to the idea that morphology is a key player in becoming a skilled reader. Children's ability to detect and use morphological units increases steadily across reading development. In addition, current theoretical models on reading development agree that processing morphological information has an important, functional role in developing stable lexical representations that can then be used during online processing.

Despite the vast research summarized above, some issues remain open. For example, as reflected in the work discussed, most research has been conducted on Indo-European languages, and some studies have also investigated Semitic languages. However, these languages all use alphabetic writing systems. Research on syllabic or logographic writing systems is rare, but would be fruitful given that they can provide interesting insights into both universal and language-specific processes.

As far as models of reading development are concerned, the available empirical evidence provides strong motivation for computational implementations of these models. This would be particularly useful for making new, explicit predictions, which could then be tested through computer simulations and evaluated against human data.

Another important issue concerns uncertainty about the effectiveness of morphological training programs. Further studies are needed to investigate different types of interventions with tightly controlled designs. Programs should be tailored to specific languages and orthographic systems. In addition, it is not only important to establish whether a morphological training program is effective or not, but also to assess (a) which *aspect* of morphological knowledge (explicit or implicit) is relevant for the outcome and (b) whether targeted interventions could have an impact on *how* morphological processing occurs.

Last, we would like to draw attention to the limited number of longitudinal studies of online processing. Even though meta-linguistic morphological skills were investigated in a longitudinal fashion 20 years ago (e.g., Casalis & Louis-Alexandre, 2000), there have only been a handful of studies investigating online morphological processing longitudinally (e.g., Hasenäcker et al., 2020). This could also help bridge aspects of morphological knowledge and online processing.

References

Angelelli, P., Marinelli, C. V., & Burani, C. (2014). The effect of morphology on spelling and reading accuracy: A study on Italian children. *Frontiers in Psychology*, 5. doi:10.3389/fpsyg.2014.01373.

Anglin, J. M. (1993). *Vocabulary development: A morphological analysis*. Chicago: Society for Research in Child Development.

Apel, K., 2014. A comprehensive definition of morphological awareness. *Topics in Language Disorders*, 34(3), 197–209. doi:10.1097/tld.0000000000000019.

Apel, K., & Diehm, E. (2014). Morphological awareness intervention with kindergartners and first and second grade students from low SES homes: a small efficacy study. *Journal of Learning Disabilities*, 47(1), 65–75. doi:10.1177/0022219413509964.

Apel, K., Diehm, E., & Apel, L. (2013). Using multiple measures of morphological awareness to assess its relation to reading. *Topics in Language Disorders*, 33(1), 42–56. doi:10.1097/tld.0b013e318280f57b.

Berko, J. (1958). The child's learning of English morphology. *WORD*, 14, 150–177. doi:10.1080/00437956.1958.11659661.

Beyersmann, E., Castles, A., & Coltheart, M. (2012). Morphological processing during visual word recognition in developing readers: Evidence from masked priming. *The Quarterly Journal of Experimental Psychology*, 65(7), 1306–1326. doi:10.1080/17470218.2012.656661.

Beyersmann, E., Grainger, J., Casalis, S., & Ziegler, J. C. (2015). Effects of reading proficiency on embedded stem priming in primary school children. *Journal of Experimental Child Psychology*, 139, 115–126. doi:10.1016/j.jecp.2015.06.001.

Beyersmann, E., Mousikou, P., Schroeder, S., Javourey-Drevet, L., Ziegler, J. C., & Grainger, J. (2021). The dynamics of morphological processing in developing readers: A cross-linguistic masked priming study. *Journal of Experimental Child Psychology*, 208, 105140. doi:10.1016/j.jecp.2021.105140.

Bowers, J. S., & Bowers, P. N. (2018). Progress in reading instruction requires a better understanding of the English spelling system. *Current Directions in Psychological Science*, 27 (6), 407–412. doi:10.1177/09637 21418 773749.

Bowers, P. N., Kirby, J. R., & Deacon, S. H. (2010). The effects of morphological instruction on literacy skills. *Review of Educational Research, 80*(2), 144–179. doi:10.3102/0034654309359353.

Burani, C., Marcolini, S., De Luca, M., & Zoccolotti, P. (2008). Morpheme-based reading aloud: Evidence from dyslexic and skilled Italian readers. *Cognition*, 108(1), 243–262. doi:10.1016/j.cognition.2007.12.010.

Burani, C., Marcolini, S., & Stella, G. (2002). How early does morpholexical reading develop in readers of a shallow orthography? *Brain and Language*, 81(1–3), 568–586. doi:10.1006/brln.2001.2548.

Burani, C., Marcolini, S., Traficante, D., & Zoccolotti, P. (2018). Reading derived words by Italian children with and without dyslexia: The effect of root length. *Frontiers in Psychology*, 9. doi:10.3389/fpsyg.2018.00647.

Carlisle, J. F. (1995). Morphological awareness and early reading achievement. In L. B. Feldman (Ed.), *Morphological aspects of language processing* (pp. 189–209). Hillsdale, NJ: Erlbaum.

Carlisle, J. F. (2000). Awareness of the structure and meaning of morphologically complex words: Impact on reading. *Reading and Writing*, 12(3), 169–190. doi:10.1023/A:1008131926604.

Carlisle, J. F., & Fleming, J. (2003). Lexical processing of morphologically complex words in the elementary years. *Scientific Studies of Reading*, 7(3), 239–253. doi:10.1207/s1532799xssr0703_3.

Casalis, S., & Louis-Alexandre, M.-F. (2000). Morphological analysis, phonological analysis and learning to read French: A longitudinal study. *Reading and Writing: An Interdisciplinary Journal*, 12(3–4), 303–335. doi:10.1023/A:1008177205648.

Casalis, S., Quémart, P., & Duncan, L. G. (2015). How language affects children's use of derivational morphology in visual word and pseudoword processing: Evidence from a cross-language study. *Frontiers in Psychology, 6*. doi:10.3389/fpsyg.2015.00452.

Castles, A., Rastle, K., & Nation, K. (2018). Ending the reading wars: Reading acquisition from novice to expert. *Psychological Science in the Public Interest, 19*(1), 5–51. doi:10.1177/1529100618772271.

Cho, J.-R., Chiu, M. M., & McBride-Chang, C. (2011). Morphological awareness, phonological awareness, and literacy development in Korean and English: A 2-year longitudinal study. *Scientific Studies of Reading*, 15(5), 383–408. doi:10.1080/10888438.2010.487143.

Colé, P., Bouton, S., Leuwers, C., Casalis, S., & Sprenger-Charolles, L. (2012). Stem and derivational-suffix processing during reading by French second and third graders. *Applied Psycholinguistics*, 33(1), 97–120. doi:10.1017/S0142716411000282.

Crosson, A. C., McKeown, M. G., Moore, D.W., & Ye, F. (2019). Extending the bounds of morphology instruction: Teaching Latin roots facilitates academic word learning for English learner adolescents. *Reading & Writing*, 32, 689–727. doi:10.1007/s11145-018-9885-y.

Dawson, N., Rastle, K., & Ricketts, J. (2018). Morphological effects in visual word recognition: Children, adolescents, and adults. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 44(4), 645–654. doi:10.1037/xlm0000485.

Deacon, S. H., Kieffer, M. J., & Laroche, A. (2014). The relation between morphological awareness and reading comprehension: Evidence from mediation and longitudinal models. *Scientific Studies of Reading*, 18(6), 432–451. doi:10.1080/10888438.2014.926907.

Deacon, S. H., Whalen, R., & Kirby, J. R. (2011). Do children see the danger in dangerous? Grade 4, 6, and 8 children's reading of morphologically complex words. *Applied Psycholinguistics*, 32(3), 467–481. doi:10.1017/S0142716411000166.

Devonshire, V., Morris, P., & Fluck, M. (2013). Spelling and reading development: The effect of teaching children multiple levels of representation in their orthography. *Learning and Instruction*, 25, 85–94. doi:10.1016/j.learninstruc.2012.11.007.

De Zeeuw, M., Schreuder, R., & Verhoeven, L. T. W. (2014). Lexical processing of nominal compounds in first- and second-language learners across primary grades. *Writing Systems Research*, 7(2), 133–156. doi:10.1080/17586801.2014.926806.

Ehri, L. C. (2005). Learning to read words: Theory, findings, and issues. *Scientific Studies of Reading*, 9(2), 167–188. doi:10.1207/s1532799xssr0902_4.

Ehri, L. C. (2014). Orthographic mapping in the acquisition of sight word reading, spelling memory, and vocabulary learning. *Scientific Studies of Reading*, 18(1), 5–21. doi:10.1080/10888438.2013.819356.

Forster, K. I., & Davis, C. (1984). Repetition priming and frequency attenuation in lexical access. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 10(4), 680–698. doi:10.1037/0278-7393.10.4.680.

Frith, U. (1986). A developmental framework for developmental dyslexia. *Annals of Dyslexia*, 36, 69–81. doi:10.1007/BF02648022.

Gellert, A. S., Arnbak, E., Wischmann, S., & Elbro, C. (2020). Morphological intervention for students with limited vocabulary knowledge: Short-and long-term transfer effects. *Reading Research Quarterly*, 56(3), 583–601. doi:10.1002/rrq.325.

Goodwin, A. P. (2016). Effectiveness of word solving: Integrating morphological problem-solving within comprehension instruction for middle school students. *Reading and Writing, 29*(1), 91–116. doi:10.1007/s11145-015-9581-0.

Goodwin, A. P., & Ahn, S. (2013). A meta-analysis of morphological interventions in English: Effects on literacy outcomes for school-age children. *Scientific Studies of Reading, 17*(4), 257–285. doi:10.1080/10888438.2012.689791.

Grainger, J., & Beyersmann, E. (2017). Edge-aligned embedded word activation initiates morpho-orthographic segmentation. *Psychology of Learning and Motivation*, 67, 285–317. doi:10.1016/bs.plm.2017.03.009.

Hasenäcker, J., Beyersmann, E., & Schroeder, S. (2020). Morphological priming in children: Disentangling the effects of school-grade and reading skill. *Scientific Studies of Reading*, 24 (6), 484–499. doi:10.1080/10888438.2020.1729768.

Hasenäcker, J., & Schroeder, S. (2017). Syllables and morphemes in German reading development: Evidence from second-graders, fourth-graders and adults. *Applied Psycholinguistics, 38(3)*, 733–753. doi:10.1017/S0142716416000412.

Hasenäcker, J., Schröter, P., & Schroeder, S. (2017). Investigating Developmental Trajectories of Morphemes as Reading Units in German. *Journal of Experimental Psychology: Learning, Memory, and Cognition, 43(7)*, 1093–1108. doi:10.1037/xlm0000353.

Hasenäcker, J., Solaja, O., & Crepaldi, D. (2021). Does morphological structure modulate access to embedded word meaning in child readers? *Memory & Cognition* 49(7), 1334–1347. doi:10.3758/s13421-021-01164-3.

Kirby, J. R., Deacon, S. H., Bowers, P. N., Izenberg, L., Wade-Woolley, L., & Parrila, R. (2011). Children's morphological awareness and reading ability. *Reading and Writing*, 25(2), 389–410. doi:10.1007/s11145-010-9276-5.

Krott, A., & Nicoladis, E. (2005). Large constituent families help children parse compounds. *Journal of Child Language*, 32(1), 139–158. doi:10.1017/S0305000904006622.

Kuo, L., & Anderson, R. C. (2006). Morphological awareness and learning to read: A cross-language perspective. *Educational Psychologist*, 41(3), 161–180. doi:10.1207/s15326985ep4103_3.

Levesque, K. C., Breadmore, H. L., & Deacon S. H. (2021). How morphology impacts reading and spelling: Advancing the role of morphology in models of literacy development. *Journal of Research in Reading, 44*(1), 10–26. doi:10.1111/1467-9817.12313.

Levesque, K. C., Kieffer, M.J., & Deacon, S.H. (2019). Inferring meaning from meaningful parts: The contributions of morphological skills to the development of children's reading comprehension. *Reading Research Quarterly*, 54(1), 63–80. doi:10.1002/rrq.219.

Levin, I., Ravid, D. & Rapaport, S. (1999). Developing morphological awareness and learning to write: A two-way street. In T. Nunes (Ed.), *Learning to read: An integrated view from research and practice* (pp.77–104). Dordrecht: Kluwer.

Mahony, D., Singson, M., & Mann, V. (2000). Reading ability and sensitivity to morphological relations. *Reading and Writing*, 12(3–4), 191–218. doi:10.1023/a:1008136012492.

Marcolini, S., Traficante, D., Zoccolotti, P., & Burani, C. (2011). Word frequency modulates morpheme-based reading in poor and skilled Italian readers. *Applied Psycholinguistics*, 32(3), 513–532. doi:10.1017/s0142716411000191.

McCutchen, D., Green, L., & Abbott, R. D. (2008). Children's morphological knowledge: Links to literacy. *Reading Psychology*, 29(4), 289–314. doi:10.1080/02702710801982050.

McCutchen, D., & Logan, B. (2011). Inside incidental word learning: Children's strategic use of morphological information to infer word meanings. *Reading Research Quarterly*, 46 (4), 334–349. doi:10.1002/RRQ.003.

Mousikou, P., Beyersmann, E., Ktori, M., Javourey-Drevet, L., Crepaldi, D., Ziegler, J. C., Grainger, J., & Schroeder, S. (2020). Orthographic consistency influences morphological processing in reading aloud: Evidence from a cross-linguistic study. *Developmental Science*, 23(6). doi:10.1111/desc.12952.

Muroya, N., Inoue, T., Hosokawa, M., Georgiou, G. K., Maekawa, H., & Parrila, R. (2017). The role of morphological awareness in word reading skills in Japanese: A within-language cross-orthographic perspective. *Scientific Studies of Reading*, 21(6), 449–462. doi:10.1080/10888438.2017.1323906.

Nation, K. (2009). Form-meaning links in the development of visual word recognition. *Philosophical Transactions of the Royal Society B: Biological Sciences*, 364, 3665–3674. doi:10.1098/rstb.2009.0119.

Nunes, T., Bryant, P., & Bindman, M. (1997). Morphological spelling strategies: Developmental stages and processes. *Developmental Psychology*, 33(4), 637–649. doi:10.1037//0012-1649.33.4.637.

Perfetti, C.A. (2007). Reading ability: Lexical quality to comprehension. *Scientific Studies of Reading*, 11(4), 357–383. doi:10.1080/10888430701530730.

Quémart, P., Casalis, S., & Colé, P. (2011). The role of form and meaning in the processing of written morphology: A priming study in French developing readers. *Journal of Experimental Child Psychology*, 109(4), 478–496. doi:10.1016/j.jecp.2011.02.008.

Quémart, P., Casalis, S., & Duncan, L. G. (2012). Exploring the role of bases and suffixes when reading familiar and unfamiliar words: Evidence from French young readers. *Scientific Studies of Reading*, 16(5), 424–442. doi:10.1080/10888438.2011.584333.

Rastle, K. (2018). The place of morphology in learning to read in English. *Cortex*, 116, 45–54. doi:10.1016/j.cortex.2018.02.008.

Rastle, K., & Davis, M. H. (2008). Morphological decomposition based on the analysis of orthography. *Language and Cognitive Processes*, 23(7–8), 942–971. doi:10.1080/01690960802069730.

Rastle, K., Davis, M. H., Marslen-Wilson, W. D., & Tyler, L. K. (2000). Morphological and semantic effects in visual word recognition: A time-course study. *Language and Cognitive Processes*, 15(4–5), 507–537. doi:10.1080/01690960050119689.

Reed, D. K. (2008). A synthesis of morphology interventions and effects on reading outcomes for students in grades K–12. *Learning Disabilities Research & Practice*, 23(1), 36–49. doi:10.1111/j.1540-5826.2007.00261.x.

Schiff, R., Raveh, M., & Fighel, A. (2012). The development of the Hebrew mental lexicon: When morphological representations become devoid of their meaning. *Scientific Studies of Reading*, 16(5), 383–403. doi:10.1080/10888438.2011.571327.

Segbers, J., & Schroeder, S. (2017). How many words do children know? A corpus-based estimation of children's total vocabulary size. *Language Testing*, 34(3), 297–320. doi:10.1177/0265532216641152.

Seidenberg, M. S. (2005). Connectionist models of word reading. *Current Directions in Psychological Science*, 14(5), 238–242. doi:10.1111/j.0963-7214.2005.00372.x.

Seymour, P. H. K. (2005). Early reading development in European orthographies. In M. J. Snowling, & C. Hulme (Eds.), *The science of reading: A handbook* (pp. 296–315). Hoboken, NJ: Blackwell.

Tibi, S., & Kirby, J. R. (2017). Morphological awareness: Construct and predictive validity in Arabic. *Applied Psycholinguistics*, 38(5), 1019–1043. doi:10.1017/s0142716417000029.

Tong, X., McBride-Chang, C., Shu, H., & Wong, A. M. (2009). Morphological awareness, orthographic knowledge, and spelling errors: Keys to understanding early Chinese literacy acquisition. *Scientific Studies of Reading*, 13(5), 426–452. doi:10.1080/10888430903162910.

Traficante, D., Marcolini, S., Luci, A., Zoccolotti, P., & Burani, C. (2011). How do roots and suffixes influence reading of pseudowords: A study of young Italian readers with and without dyslexia. *Language and Cognitive Processes*, 26(4–6), 777–793. doi:10.1080/01690965.2010.496553.

INDEX

Page numbers in italics refer to figures. Page numbers in bold refer to tables. Page numbers followed by 'n' refer to notes.