Christina Manouilidou

Experimental approaches to morphology

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DEDICATION

To my mom and dad, with all my love

Στη μαμά μου Ξανθούλα και τον μπαμπά μου Νίκο με όλη μου την αγάπη

Preface

When I was told that the only requirement I am missing to be promoted to the rank of full professor is producing a monograph, I was rather disappointed, and for quite some time, I refused to do so. As the idea began to mature in my mind, the difficult task of choosing what to write about arose. I had numerous thoughts, some discussions with friends and colleagues, and then the obvious choice occurred to me. Experimental approaches to morphology! This is the most significant aspect of my academic life. I could write it in my sleep, I thought. Alas, it was such a challenging task. The writing of this book was completed in approximately one year, a time that was also shared with my other academic activities, such as teaching, mentoring, and research projects. It has gone through many phases, all of them characterized by love-and-hate feelings. However, it is now complete, and it summarizes the topics I have explored in my work related to morphology and its processing.

The monograph presents the main findings of psycholinguistic and neurolinguistic research on morphological processing and complex word recognition. It approaches morphology through the framework of the generative lexicon, providing experimental evidence on the processing of three distinct morphological operations: inflection, derivation, and compounding. The monograph focuses on three axes: evidence from behavioral psycholinguistic experiments conducted on adults, evidence from cutting-edge neuroimaging studies, and, finally, evidence from populations with language disorders. This last dimension is especially valuable as it is very rarely considered in similar works. Of particular interest is the inclusion of neurodegenerative conditions, in which the domain of morphology is hardly investigated. The result is a broad, but not exhaustive, view of morphological processing, as outlined through current experimental approaches, considering a wide, cross-linguistic perspective.

I address big-picture questions, touching upon theoretical issues on morphology, theories of lexical processing, and issues of neuroanatomical substrates of morphological processes. Among them is the relationship of the three morphological operations seen through experimental evidence, the processing route of complex word recognition, and the role of various linguistic and extra-linguistic variables. I also addressed more specific ones, such as the time course of activation of specific processes, the brain locus of morphological operations, and patterns of morphological loss in various brain damage conditions. The answers were not always obvious, and I deliberately avoided firm conclusions when in doubt. As such, the current monograph primarily highlights the 'clear' but also the 'unclear' aspects of research on morphological processing, posing specific questions for future investigations.

As a growing interest of mine evolves around therapy and intervention techniques, it only seems natural to start thinking about morphology as a domain of intervention, and at the same time as a tool as well. Thus, I have developed some thoughts on these issues, which are outlined in the final chapter. This inclusion enhances the interdisciplinary perspective of the monograph and adds an applied touch. Even though it is still sketchy, I hope it inspires people doing clinical work to look at the findings of experimental psycholinguistic and neurolinguistic research.

I hope that the monograph will become a useful tool for a variety of audiences. For students and professors of psycholinguistics and neurolinguistics, it can serve as a starting point and work of reference. For theoretical linguists, it can provide a foundation for experimental answers to theoretical issues, such as the distinction between morphological operations and the psychological reality of theoretical notions. Finally, clinicians might turn to the monograph to consult on neurolinguistic results of pathological populations and incorporate them in their daily practice.

Christina Manouilidou
Nova Gorica, 5. 9. 2025

Acknowledgements

As this project of writing a monograph comes to an end, there are several people whose help and assistance I would like to acknowledge.

First, I'm grateful to Petra Mišmaš and Marko Simonović for their trust in me that the sketch they saw can turn into a book. I thank the Publishing House of the Faculty of Arts (Znanstvena Založba Filozofske fakultete) and, in particular, Jure Preglau for ensuring the publishing process went smoothly. I thank ARIS (Slovenian Research and Innovation Agency) for financing this publication.

While thinking about and writing the monograph, I had financial support from the following projects: SAVANT (ESRC), CogLiTreat (ARIS, J6-1806), and NeDiS (ARIS, J6-50200). Most importantly, through these projects, I had a continuous flow of ideas through discussions about morphology and its processing with all my collaborators involved in them, and I'm really grateful for this opportunity.

I particularly want to thank the following colleagues who read various sections of the book and provided generous and constructive comments: Phaedra Royle, Linnaea Stockall, Michaela Nerantzini, Monica Norvik, Ifigeneia Dosi, Seckin Arslan, Valantis Fyndanis, and Karsten Steinhauer. The work of some of my PhD students, former and current, was taken into consideration, especially the work of Konstantina Kordouli on compound processing.

As this is my first official book (and probably the last one), several people come to mind who deserve mentioning because they laid the foundations for this book: Niki Kosmidou, my first teacher, who had a tremendous impact on me and on the way I viewed school and learning. Niki Christodoulou, my high school philologist, who inspired me in everything related to language. Anna Anastasiadis-Symeonidis, the person who taught me morphology and stood by me every step of the way. Eva Kehayia, the person who taught me how to investigate morphological questions through experiments. Eta Schneiderman, the person who taught me how to write academically. Without these five amazing women, this book would have never been realized.

As I'm writing these lines, the name of Gary Libben, who left us earlier this year, comes to my mind. Gary has influenced my thinking on complex word processing, and I feel that he has a share in this book, too.

Lastly, I'd like to thank my immediate entourage: Rok, my mom and dad, my sister and her crew, and my extended entourage, friends and colleagues from around the globe who kept asking 'how is the book going?', and those who wanted to ask and did not do so because they did not want to stress me out.

And of course, thanks to my Melisa, who inspires me in everything I do.

1 Introduction[1]

In recent years, the study of human language performance has been the focus of interdisciplinary research, bringing together work on linguistics, cognitive neuroscience, and psychology. Psycholinguistics has been at the centre of this research, with the primary aim of elucidating the mental processes that enable the comprehension and production of grammatical and meaningful sentences from a set of vocabulary and grammatical structures. A thorough understanding of human language necessitates examining the mental representations that underlie language ability. Various theories and models of language production and comprehension have focused on describing both the form and content of mental representations, as well as how lexically stored knowledge is applied during online language processing. The study of the *mental lexicon* is at the centre of much of this work, as it is viewed as central to language processing and a locus of computation, where form is connected to meaning via the mental representations of individual words.

Despite considerable progress in understanding the mental lexicon, significant controversy remains regarding its organization and the types of information it contains. The goal of the present monograph is to contribute to our understanding of the mental lexicon and, particularly, to our knowledge of how morphologically complex words are represented and accessed. But what are *morphologically complex words*, and why is their study meaningful when one is interested in the mental lexicon? In 2016, Brysbaert and colleagues published a study in which they claimed that the average educated American English speaker knows about 48,000 words by the age of 60. If you asked Gary Libben *how we are able to create so many words*, he would tell you that in strictly computational terms, the answer is simple: "We just make them longer" (Libben, forthcoming). This is where morphology begins, and where its study becomes meaningful when one is interested in figuring out what is going on in the mental lexicon.

A morphologically complex word is made up of more than one constituent unit, i.e., more than one *morpheme.* The relationship between morphemes

1 The current Introduction is a modified version of the Introduction found in my doctoral thesis *On the processing of thematic features of deverbal nominals*, University of Ottawa, 2006

can be simple or rather complicated, varying in degree of *morphological complexity*. That is, it can be governed by morphological rules that determine how morphemes combine to form words. It can be a structural, semantic, or even a functional relationship. Each of these options creates a unique combination that leads to different types of complex words and a different set of questions associated with them. Among them, the most fundamental question in the study of morphology and the mental lexicon is whether words are *decomposed*, that is, whether they are represented and processed in terms of their smaller constituent units. While this idea may seem straightforward, formally defining what it means to represent or process a word as decomposed is considerably more complex, and I will address this later in the book. Various psycholinguistic models have been proposed (see Chapter 2), which enable us to clarify ideas and relations in a manner that deepens our understanding of the relationship between morphology and the mental lexicon. However, such models tend to remain in the realm of abstraction, and this is where the need for experimental verification arises. This book aims to bring to light experimental evidence that contributes to a deeper understanding of the relationship between morphological processes and the mental lexicon. It will also reveal the necessity for a set of research questions that are more refined than a simple "decomposition-or-not" dichotomy.

The following sections provide a brief overview of various linguistic and psycholinguistic proposals regarding the lexicon, with a focus on morphologically complex words. Their presentation is intended to provide the general framework for the present monograph.

1.1 The lexicon in theoretical linguistics

Even before the advent of psycholinguistically motivated research, the mental lexicon, known simply as the *lexicon*, already held a place in linguistic theory. Almost every linguistic theory, whether its focus is on syntax, semantics, phonology, or word formation, postulates the existence of a component of the grammar called the *lexicon*. However, these theories vary significantly in their descriptions of the lexicon's organization and the types of information it contains. For instance, theories may differ with respect to what they consider as the minimal representational units within the lexicon, e.g. roots, words, or feature bundles, and the type of information encoded with them. They also diverge regarding other properties of the lexicon, e.g. its role in word formation and its interaction with other components of the grammar, such as syntax. For instance, while Lexicalism treats the lexicon as the central component of word formation, including words, roots, affixes, and a set of word formation rules, Distributed Morphology views the lexicon in a very narrow sense. It only includes atomic roots (sound-meaning pairings) and feature bundles (Halle & Marantz, 1993). Closer to Lexicalism than to Distributed Morphology, but still with more emphasis on the role of the lexicon in generating not only new words but also syntactic structure, a *generative lexicon* is viewed as a dynamic system that contains both roots and words, as well as various sets of rules; it is considered the locus of computation. The generative lexicon presupposes a robust computational model in which not only new forms, but also new meanings are derived through computation.

The development of generative approaches to the lexicon can be traced through the work of Noam Chomsky. Over the past 60 years, the Chomskyan perspective has evolved and changed with respect to the status and role of the lexicon. In the very early versions of Chomsky's model (1965), the lexicon was not recognized as an autonomous component of the grammar. Moreover, lexical entries were limited to a minimal form with specifications of no more than inherent and selectional features. However, over time, increasing importance has been ascribed to both the lexicon as a component of grammar and the nature of lexical entries.

With the formulation of the Government and Binding (GB) theory (Chomsky, 1981), the lexicon began to be seen as one of the four subcomponents of grammar[2] and was considered to exert a crucial influence on syntactic structure. The 'projection principle' of GB postulates that the properties of lexical entries are 'projected onto' syntax. These properties include a representation of the phonological form of each item, a specification of its syntactic category, and its semantic characteristics (the semantic selection and thematic properties of lexical heads). The same properties also specify the argument structure of a head, indicating how many arguments

2 The other three are the *syntactic* (categorial and transformational) *phonological* and *logical* components.

a head licenses and what semantic role each receives. Thus, GB specifies a rich set of information in lexical entries.

In the *Minimalist Program* (Chomsky, 1993, 1995a, 1995b), the four subcomponents of the grammar are substituted by two 'interface levels', Phonological and Logical form. Both the D-structure, which, in the previous model, was assumed to be projected from the lexicon, and the S-structure have been eliminated. Instead, the status of the lexicon seems to be further enhanced, since the whole process of deriving a syntactic structure is represented as beginning in the lexicon. This means that the lexical entries, after being retrieved from the lexicon and having been transformed into phrases, are transferred into grammatical derivations. The lexical items, which are selected in any given sentence, are the determinants of both the content and the form of the sentence. This implies that the lexicon has grown in importance to the point that some linguists now claim that acquiring the lexicon is almost all a child needs to do to acquire a language. Everything else is generated by a strictly invariant computational system, specific to language, and by the several output conditions at the interfaces of this computational system with other internal mental systems. The Minimalist Program is indicative of the increasing importance that current generative views attribute to the lexicon, which is seen as a dynamic component including lexical entries with rich information. Minimalism paved the way for the development of a lexicon-oriented linguistic model.

Similar approaches to the lexicon have been proposed in various generative theories. Head-driven Phrase Structure Grammar, developed by Pollard and Sag (1987, 1994), views words as extremely rich in grammatical information and as playing a key role in determining the syntactic shape of the sentences in which they occur. Lexical Functional Grammar, developed by Bresnan (1982, 2001), also considers the lexicon to be right at the heart of syntax. Every item in the lexicon comes equipped with indicators of how it sounds or how it is signed, and what it means. In the case of a verb, additional indicators determine the roles of the elements that are structured around it in a given sentence (its argument structure) and the grammatical functions assigned to these roles. Lexical choice is the shaper of the syntax of any given sentence. Goldberg's (1995) Construction Grammar attributes to individual lexical items all the information needed for the construction of linguistic structures or utterances. In addition to lexical items, she postulates form-meaning correspondences to exist in the language user's mental lexicon in the form of constructions. She considers constructions to be necessarily motivated by the lexical entries that typically occur in them.

In this monograph, I adopt a generative approach to the lexicon, which entails the existence of rich lexical entries for each lexical item. This approach further assumes that a lexical entry is specified for the abstract morpho-phonological structure of each lexical item and its associated syntactic features. More specifically, the lexical entry of an item, in its richest possible representation, includes information about meaning, syntactic category, grammatical features (number, person, tense, etc.), morphological structure (simple, derived, compound), subcategorization (configurational information), its predicate argument structure (thematic information), its cases (of its possible arguments), and register (style). The above knowledge is present in the speaker's mind and is accessible when a lexical entry is activated. What is left to be seen is how much of this knowledge is accessed, consciously or unconsciously, by the speakers each time they activate a lexical entry. In other words, how much of this knowledge is processed before the speaker confidently accesses a mental representation? The following section is a brief introduction to the mental lexicon, the locus of this computation, and the basic assumptions underlying existing research on it.

1.2 From the lexicon to the mental lexicon

In the previous section, I briefly presented various theoretical views on the role of the lexicon in grammatical knowledge/competence. As shown earlier, a generative approach presupposes the existence of a rich, autonomous, multi-module, and multi-level lexicon, where all pertinent information about the word is stored in the lexical entry. In this section, I will introduce another dimension of the lexicon, often referred to as the *mental lexicon*. Like the lexicon, the mental lexicon represents the internalized knowledge of word properties. Its 'mental' dimension derives from the fact that it is seen not only as a subcomponent of the language system, but also as part of general human cognition and a cognitive network in its own right. This is closely related to the fact that the mental lexicon is typically studied from the perspective of language use or *performance*. Thus, the term mental lexicon is used to describe the dynamic organization of words in the mind, comprising a vast and complex network of mental representations, associations, and cognitive processes.

Research on the mental lexicon has focused on a number of questions that aim at capturing both the common and variable aspects of lexical representation and processing across languages. Primary among them is the issue of *what is listed* in the mental lexicon (in terms of minimal units and the information encoded) and how *mental representations are accessed* and linked to each other. Experimental research has approached the above questions from various perspectives and through a variety of means, including investigations of the online and offline performance of non-impaired and brain-damaged populations in multiple languages, utilizing a wide range of techniques. The central focus is always human performance and its various manifestations, which are often task-dependent. For instance, cross-population research has enabled us to compare non-pathological and pathological language processing, investigating the types of representations that are lost due to brain damage, as well as which representational information within lexical entries is no longer accessible through normal processing channels. Furthermore, the study of the bilingual lexicon provides an opportunity to distinguish between universal and language-specific effects, as it allows us to examine language-specific processing in the same individual. Ultimately, cross-linguistic investigations have significantly advanced our understanding of the relationship between linguistic diversity and psycholinguistic and neurolinguistic variation. For instance, comparing language processing or language breakdown in fundamentally different linguistic systems has allowed us to investigate hypotheses about how language-specific parameters shape lexical representation, organization, and functioning, thus bringing us closer to an understanding of language universals.

Investigations of the online performance of non-brain-damaged monolingual populations have been the central focus of research on the mental lexicon. Although many studies have focused on spoken word recognition, many others have concentrated on the visual processing of written words. Research on visual word recognition has employed a variety of methods, with the major paradigm being visual lexical decision tasks (LDTs). To understand the nature of lexical representations in monolingual, non-brain-damaged populations, one of the significant challenges within the lexical decision paradigm has been to tease out the differential effects on lexical processing of various lexical properties. These properties refer to the specific phonological, morphological, semantic, and syntactic characteristics of the stimuli. Manipulations targeting the relative effects of morphology, phonology, semantics, and syntax enable us to probe subtle aspects of lexical representation that would otherwise be undetectable. For instance, by comparing individuals' performance in accessing derived versus non-derived words, one can draw conclusions about the effect of complex morphological structure in lexical access and, consequently, about the mental representation of these two types of words.

Indeed, as I will show in the following chapters, experimental evidence leaves no doubt that morphological information is represented in the mental lexicon in quite a detailed way (see Chapter 3). Moreover, despite some controversy on the time course of activation of phonology, evidence converges to suggest that phonological information plays a role in word recognition and the organization of the lexicon (e.g. Grainger & Ferrand, 1996). Similarly, several reports in the literature suggest that semantic variables, such as concreteness, imageability, and polysemy, influence the recognition process (e.g. Zevin & Balota, 2000). The role of syntactic features has been studied to a lesser extent, typically with a focus on the effects of grammatical class and verb argument structure. Grammatical class has been shown to affect lexical access, and evidence coming principally from the literature on aphasia suggests that the lexicon is organized based on this type of information (e.g. Bradley et al., 1980; Berndt et al., 1997). Verb argument structure and its general thematic information also appear to be accessed immediately upon encountering a verb (e.g. Mauner & Koenig, 1999).

Despite all this knowledge, a major concern remains in investigating how these various features interact with each other in visual word recognition. For instance, to what extent is semantic transparency necessary for accessing derived forms after they have been decomposed into their constituents? Also, what is the effect of non-linguistic features, such as the frequency of occurrence of a particular item, on the speed and the means of its lexical access? The present monograph was conceived against this general background to provide an overview of issues pertaining to lexical access and the representation of complex words. The goal is to highlight experimental evidence that will help us determine how a complex morphological structure interacts with other word features, and how we can use this knowledge to advance our understanding of language processing.

1.3 Goals and orientation of the present monograph

The goal of the present monograph is to create a platform for discussion by presenting a comprehensive perspective on morphological processing which encompasses all morphological subfields – that is inflection, derivation and compounding – and which considers and evaluates experimental data of various techniques, i.e. behavioral and neuroimaging, on a variety of populations, ranging from healthy adults to people with brain damage. Of particular importance is the evidence from populations with neurodegenerative conditions, as they are usually not considered in similar approaches.

The three morphological subfields –inflection, derivation, and compounding– represent distinct morphological processes. They all use morphemes to create new lexical items, but they are fundamentally different from each other, both with regard to the type of morphemes they are using (stems, inflectional affixes, derivational affixes) as well as the final product, either being a functional/grammatical modification of the stem – something which falls within *inflection* or a new lexical item, usually related in meaning to the stem/stems – in the case of *derivation* and *compounding*. Thus, while the ability to understand and produce inflectional forms may rely on grammatical/morphosyntactic processing, the ability to understand and produce derivational forms may rely on lexical retrieval and semantic processing. Given these fundamental differences, it could be that the underlying cognitive systems used to process these different types of information are also distinct. Indeed, research has shown that derivational morphology typically involves more complex mental processes than inflectional morphology. This claim is further supported by the fact that derivational morphology is acquired later than inflectional morphology, and its development goes hand in hand with the development of nonverbal reasoning skills (Diamanti et al., 2018; Ger et al., 2025). A comprehensive view of morphological processes should thus consider these processes separately but also contractively, and this is one of the goals of the current monograph.

A second goal is related to the use of the various experimental paradigms and techniques. Psycholinguistics as a discipline employs a number of ways in order to understand language processing. These range from behavioral studies, particularly studies employing chronometrized methods, such as reaction time (RT) paradigms, to neuroimaging techniques. Even though this will not be addressed as a separate chapter, one of the goals of the monograph is to highlight what each methodology brings to light with respect to morphological processing, with the aim of providing guidelines for future research.

Related to this, the present monograph draws attention to the importance of looking at the brain, both in real-time and through lesion studies. The advent of neuroimaging techniques has led to a flowering of new research in psycholinguistics. Technologies that allow us to measure electrical activity in the brain have provided valuable data, similar to techniques that measure the changes in the blood flow after a stimulus. Finally, examining the behavioral limitations of individuals with brain lesions or brain atrophy can provide valuable information about which regions are responsible for which behavior, and specifically morphological behavior in our case. At the end, I will try to make sense of all relevant evidence in terms of linguistic and psycholinguistic theories, and I will develop some thoughts on the use of morphology in clinical practice.

1.4 Monograph outline

In Chapter 2, I provide an overview of the primary psycholinguistic models related to lexical access and representation of complex words. The chapter outlines clear research questions regarding morphological processing and paves the way for the experimental work presented in the following chapters. In Chapter 3, I outline the major findings of these questions with respect to the processing of inflectional and derivational morphology as well as compounding in healthy adult populations. Chapter 4 addresses the question of morphological processing in the brain and the contribution of neurolinguistics towards this investigation. Cutting-edge experimental techniques have been used to examine how inflected words, derived words, and compound words are processed, and the chapter brings to light their contributions to our current knowledge. In parallel, a connection between lexical processing and brain anatomy is discussed to situate morphology and its subfields in the human brain. Chapter 5 introduces a new dimension of morphological knowledge by focusing on brain-damaged populations. I summarize the main findings of conditions resulting from brain damage, which are related to morphological processing. The chapter goes beyond the well-studied aphasia outcomes to include morphological deficits in neurodegenerative conditions as well, something which is very rarely discussed in the literature on morphological processing. Finally, the monograph ends with Chapter 6, which outlines the main conclusions and possible directions for using morphological findings of previous research in clinical applications.

2 Psycholinguistic models of morphological processing[3]

In this chapter, I briefly present the most representative models of processing and representation of morphologically complex words. As mentioned in the introduction, research on the mental lexicon seeks to better understand the nature of mental representations, how they are accessed, and how they are linked. Although research stemming from each of these separate directions attempts to delineate different aspects of the mental lexicon, they are all closely connected and interrelated. For instance, knowledge of how mental representations are accessed can provide insights into their make-up and, ultimately, information regarding the precise properties of an item listed in the mental lexicon. Within this frame, I will explore the role of morphology in the models that will be presented. There are models in which morphology plays a central role and is considered independent from phonology and semantics, and models in which morphology plays a secondary role, as it is understood and interpreted not independently but in relation to semantic and phonological similarity.

This latter group of models, in addressing the role of complex morphological structure, also considers its interaction with other lexical features that influence lexical access. Previous psycholinguistic research has identified several factors that seem to play a role in visual word recognition. These pertain to both the pure linguistic[4] and non-linguistic properties of a word. Although a typical non-linguistic property, such as word length, may play a crucial role in the speed of lexical retrieval, this does not provide us with any information regarding either the nature of the item's lexical entry or the organization of the mental lexicon in general. In contrast, the fact that such linguistic properties as complex morphological structure, phonological transparency, semantic concreteness/abstractness, ambiguity, grammatical class, and various syntactic specifications appear to influence lexical access

3 The current chapter is a modified and updated version of the second chapter of my doctoral thesis *On the processing of thematic features of deverbal nominals*, University of Ottawa, 2006.

4 Although there is much controversy regarding the types of properties that can be labelled as *linguistic* and *non-linguistic,* this distinction will be adopted as a working distinction in the present monograph. The term *linguistic* will be used to refer only to those properties of a word that can be described and explained by linguistic theory. All other lexical properties will be referred to as *non-linguistic*.

suggests that these properties may play a prominent role both in the mental representation of lexical items and in the organization of the lexicon. Keeping this in mind is essential when judging the effectiveness of each model, as well as when understanding and interpreting the experimental data that I will review in the following chapters.

2.1 The role of morphological structure in lexical access and representation

A large number of studies have been carried out to investigate the possible effects of morphological structure on lexical access, as accessing the structure of a lexical item is considered one of the first steps in the entire process of lexical access of complex items. The most fundamental question regarding the interaction between the morphological structure of complex words and their storage and access is whether they are accessed through decomposition into their constituents (e.g. *un-deni-able*) or as wholes (e.g. *undeniable*). Researchers tend to fall broadly into three different camps with respect to this question, building their supporting arguments on a foundation of somewhat conflicting research findings. In the first camp, researchers tend to cite studies indicating a decomposed representation (Taft & Forster, 1975 and references thereof), while those in the second camp prefer to cite evidence suggesting that access occurs via a stored representation of the whole word (Butterworth, 1983 and references thereof). Those in the third camp cite a broader range of studies supporting the view that both decomposed and whole word forms are available, with each being accessed under different circumstances (Caramazza et al., 1988; Chialant & Caramazza, 1995; Schreuder & Baayen, 1995).

Proponents of the first two proposals agree that accessing the lexicon relies on one mechanism (single route), although they disagree on the nature of this mechanism; all lexical items are either segmented online (morpheme-based hypothesis) or they are all learned and retrieved as wholes from memory (full-listing hypothesis). Proponents of the third proposal postulate that, depending on a variety of factors, both of these two distinct mechanisms can be available for lexical access (dual-route/hybrid models). The basic assumptions of these three morphologically based theories of lexical representation and processing are briefly reviewed in the following subsections. I will begin by presenting the two most 'extreme' hypotheses of lexical organization, the strict decomposition and full-listing hypotheses, followed by a discussion of the dual-route hypothesis, which reconciles the two.

2.1.1 The morpheme-based (decomposition) hypothesis

The morpheme-based (decomposition) hypothesis assumes that lexical access of a complex word takes place after it is decomposed into its constituents. The mechanism of morphological decomposition is automatically and necessarily applied during early, prelexical processing, and it is assumed to be semantically blind, since it only takes into account the surface morphological structure of words. That is, access to representations of constituent morphemes precedes and is a prerequisite for access to holistic representations of morphologically complex words. Depending on one's perspective, this model is either called the *decompositional hypothesis* (for those who focus on how lexical access is achieved) or the *morpheme-based hypothesis* (for those who focus on how lexical representations are organized).

In its strict version, the decomposition hypothesis was proposed by Taft and Forster (1975). Their model postulates access procedures in which all affixes of a morphologically complex word are always 'stripped off' before lexical access; in other words, this is *prelexical decomposition*. In their original experiments (Taft & Forster, 1975, 1976), which focused on the lexical access of prefixed items, the authors view the lexical access of visually presented items as a serial process consisting of several steps to be taken in a fixed sequence: the prefix is assumed to be stripped off and then a search for the stem is undertaken. If the stem can be located in the lexicon and a prefix can be added to it, then the lexical decision response is 'yes'. If the stem does not correspond to a lexical entry in the lexicon, then the lexical decision response is 'no'. They found that it took readers longer to decide that a non-word containing a real prefix is not a word than to decide on matched, unprefixed controls, e.g. *depertoire* vs *mowdflisk*.[5] They interpret this RT difference as evidence that the affixed words are stored in their base

5 An important factor that Taft & Forster did not take into consideration and were later criticized about, is that the two types of non-words do not match with respect to 'wordness'. That is, **pertoire* exists as part of a pseudo-derived word, while **mowdflisk* does not follow the phonotactic rules of English.

form and that the target of lexical access is the root, not the word as a whole (Taft & Forster, 1975).

Prelexical decomposition was supported by a series of empirical studies by the same authors, each of which contained substantial modifications of the original hypothesis (e.g. Taft & Forster, 1976; Taft, 1991, 1994, 2003, 2023), but also other groups of researchers (Rastle & Davis, 2008; Fruchter & Marantz, 2015). One of the latest developments within this group of models is the AUSTRAL model (Activation Using Structurally Tiered Representations and Lemmas), by Taft (2003, 2023). This includes three levels: the *form* level, *function* level, and *intermediate* lemma level, so that the lemma of a word mediates between its form and function (semantic-syntactic features). At the form level, there are access representations that represent only morphemes and not whole polymorphemic words. In contrast, at the level of the lemmas, there are lemmas of morphemes and lemmas of whole polymorphemic words, hierarchically structured and interconnected. In particular, each morphologically complex word has its own lemma, which is connected to the lemmas of the constituent morphemes by links of graded strength, depending on the degree of semantic transparency. The model assumes automatic decomposition after which the orthographic representations of the stem and affix are activated, subsequently activating their equivalent lemma representations. At this level, derived words are activated through the lemmas of their constituent parts (Xu & Taft, 2015). Finally, the most recent versions of full decomposition models (e.g. Fruchter & Marantz, 2015) usually assume that a *recombination* stage follows after the representations of the separate morphemes are accessed, where these representations are recombined into a complex word. Arguably, at this recombination stage, morphological rules are consulted, and the combinations of morphemes are evaluated.

The strict decomposition models received a lot of criticism for various reasons. One of them is related to its blind application to all pseudo-complex words, such as *prefer*, to highly complex words, such as *unremittingly*, or to complex but opaque words as *department* ('depart' + '-ment' ≠ 'department'). Already in 1975, Taft and Forster replied to this criticism by claiming that it is more economical to store the stem for a number of different words just once, e.g. *mit* (Taft & Forster, 1975: 646). Organization by stems also allows for semantically related words to be listed near each other, even if the lexicon is organized orthographically or phonologically. For example, *rejuvenate* and *juvenile* could appear as adjacent entries, even in an alphabetical listing, if the prefix is removed (Taft & Forster, 1975: 643). In fact, subsequent studies have shown that bound roots produce equal patterns of facilitation with free roots (e.g. Forster & Azuma, 2000), even though bound stem priming seems to depend on the distributional properties of both roots and affixes.

Another weakness of the strict decomposition theories is their failure to consider how a complex morphological structure interacts with other lexical features of the whole word and its constituent morphemes, such as frequency and transparency. As I will show in Chapter 3, the claim of automatic, obligatory and semantically blind prelexical decomposition as the only access mechanism for morphologically complex words runs up against the fact that the processing of complex items seems to be influenced by several parameters, such as: (a) the properties of words, e.g. length, stem and whole word frequency, and their interaction; (b) the overall composition of the experimental language material, e.g. the ratio of morphologically similar-dissimilar stimuli, ratio of semantically similar-dissimilar stimuli, ratio of morphologically simple-complex stimuli, types of fillers; (c) the type and requirements of the experimental test, e.g. LDT, semantic categorization task, comprehension task, same-different task; (d) the characteristics of the language under investigation, e.g. morphological richness, linear/non-linear morphology, orthographic system; and (e) the individual differences and sociolinguistic characteristics of the participants, e.g. gender, age, education, lexical ability, reading ability.

Furthermore, it is questionable whether decomposition alone is sufficient for accessing a complex lexical item. Thus, an important part of the criticism has to do with the obligatory nature of prelexical decomposition for the recognition of morphologically complex words. That is, it is claimed that the mechanism of morphological decomposition is neither obligatory nor unique, but it is merely one of the possibilities of the lexical processing system, just like other mechanisms, e.g. holistic access or the activation of embedded stems (Chialant & Caramazza, 1995; Beyersmann & Grainger, 2023; Grainger & Beyersmann, 2017; Kuperman et al., 2009; Schreuder & Baayen, 1995).

As I will show in Chapter 3, although there is evidence that decomposition does occur, there is no evidence that decomposition always occurs. As such, given all the problems with the strict decomposition view, a more realistic model would allow for the possibility of the co-existence of both decomposition and its apparent opposite, unitary access. Before describing such a hybrid model, I will first examine another extreme version of a unitary access model, which is the *whole-word* or *full-listing* hypothesis.

2.1.2 The full-listing (whole word) hypothesis

Butterworth (1983) is the foremost proponent of the full-listing hypothesis (FLH), which was originally proposed in response to Taft's (1975) stripping model. The FLH specifies that lexical access is based on the whole word, although fallback rules may apply when necessary.[6]

After an elaborate discussion pointing to evidence from speech production, speech perception, and reading, Butterworth (1983) concludes that the lexicon is most likely not organized in terms of morphemes with attendant morphological rules. Rather, due to the idiosyncrasy of semantic relationships, a full listing model is the only possible one. Such a model postulates that morphological relations are neither represented nor used in lexical access. Consequently, the lexicon is a list of words, and each lexical item is recognized as such, without decomposition into its constituents.

However, this is not in accordance with the majority of linguistic theories, such as those proposed in the framework of Lexicalism,[7] which assume that regularities in lexical representation can be captured by rules, with only idiosyncratic elements needing a listing as such in the lexicon.[8] For Butterworth, the lexicon contains every possible word, regular or irregular. For instance, the FLH implies the existence of a form like *sings* which is associated with a meaning, a major lexical category, and a list of suitable syntactic contexts (or subcategorization frames) (Butterworth, 1983: 262).

6 The model also touches on other important issues (that I will not review) such as modality and lexicon, the distinction between function and content words in the lexicon and the role of frequency in lexical organization.

7 Only Aronoff (1976) denies the existence of morphemes in the lexicon, which he claims to consist of only whole words.

8 Butterworth (1983: 261), quoting Bloomfield (1933), Chomsky (1965), and Chomsky and Halle (1968), admits that "linguists have traditionally rejected the Full Listing Hypothesis (FLH)".

Nevertheless, critics point out that the FLH seems to ignore the fact that derived words bear meanings that are predictable functions of their components. In reply to this, Butterworth (1983: 264) provides examples from derived words with diverse meanings, not all of which are predictable from the base.[9] That is, Butterworth's central argument is that some rules apply to just some lexical items, so the rules must be stated in a lexically sensitive way. Furthermore, derivatives in general have unpredictable semantics and thus constitute a major problem for a model of lexical representation that rejects the FLH. However, the role of morphemes is not altogether rejected by the FLH. For example, in a full listing model, various forms can have an internal structure marking morpheme boundaries. Thus, forms like *sings* and *singing* have separate listings, but with morphemic boundaries, *sing-s, sing-ing*.

Another criticism levelled against the FLH is that speakers produce speech errors that respect morphological boundaries (e.g. *expection* instead of *expectation*),[10] and this is something that is also found in people with language disorders (see Chapter 5). These types of errors would not arise if speakers had only listings of full words. For such cases, Butterworth (1983: 282) suggests that rules might be used as a fallback when a new word is encountered or when there is a need to coin a word if the full list fails. These rules can be 'substantive rules', which provide a recipe for constructing words. Alternatively, they can be in the form of 'meta-rules', which guide the language user to construct a new word based on already existing similar ones. By assuming the existence of such rules, Butterworth accounts for the productivity problem while still claiming that access procedures do not take place through affixes, but rather through spelling patterns and syllables. If such a proposal is true, then there would be no RT differences in LDTs between affixed and non-affixed words. Indeed, this was the finding of one of the earliest studies on lexical access by Manelis and Tharp (1977), which inspired Butterworth. They found no significant difference in RTs between suffixed (e.g. *dusty*) and non-suffixed words (e.g. *fancy*). However, this and

9 One such derivation is from the verb *induce*. This verb can have the following meanings: 'persuade', 'cause', 'produce current', 'infer from cases', 'induct'. If one examines its derivatives, it will become obvious that not all of them are associated with all of its meanings. Rather, the association between meaning and form is quite arbitrary. Consider, for example, the case of *inducible,* which is only associated with the 'infer from cases' and 'cause' meanings of *induce*.

10 Example from Cutler (1980).

any lack of a difference between suffixed and non-suffixed words do not necessarily mean that decomposition never occurs. In fact, the relevance of morphological information in lexical access is supported by a variety of studies, which show that morphological features do affect word recognition and that their effects can be separated from those of phonology and orthography (see Chapter 3). Moreover, despite the large number of convincing counterexamples to morphological regularity, the FLH ignores many morpho-semantic relations that appear to be regular and productive.

Both the decomposition model and FLH have important contributions to make to our understanding of lexical access and the organization of the lexicon. However, and not surprisingly, neither of the extreme positions (whole-word access or strict decomposition) has received unequivocal experimental support. In fact, research findings have provided support for both positions, depending, in some cases, on factors such as word frequency. Since neither a purely affix-stripping approach nor a full-listing hypothesis appears sufficient on its own, a hybrid position that integrates elements of both offers the most promising compromise. However, proposing two distinct modes of lexical access within a 'dual-route' model raises several important questions. For instance, are the two routes applied simultaneously or successively? If simultaneously, what determines the eventual success of one procedure over the other? If successively, what determines which access procedure applies in which situation or with which words? Various proposals regarding these questions are discussed below.

2.1.3 The dual-route hypothesis

Given the lack of unequivocal experimental support for each of the single-route models, a number of hybrid models have emerged in which the lexicon is seen as containing both whole words and individual morphemes. Within such a lexicon, lexical access can take place either after decomposition or through whole-word access. Such models are interesting in that they not only provide us with information on processing at the level of the morpheme, but also allow us to investigate the possible effects of specific lexical features (morphological, morphosyntactic, or phonological) during lexical access. In other words, these models take into account possible interactions between a number of factors that may affect lexical access.

There are two types of dual-route models. The first type adopts one of the extreme positions ('decomposition' or 'whole-word' access) and incorporates parts of the opposite proposal to account for special cases (e.g. the Supralexical Model, see § 2.1.3.1). The majority of dual-route models, though, belong to the second type, which is represented by models that use a mixed approach as a starting point and argue that some words or word groups are accessed directly/holistically, whereas others are decomposed (e.g. Caramazza and colleagues). There is also another subset within this second type of model, which assumes a mixed approach of decomposition and whole-word access functioning in a parallel manner, such as the meta-model put forward by Schreuder and Baayen (1995), which incorporates the main points of the earlier dual-route models.

2.1.3.1 Models assuming one route as the starting position

The model proposed by Giraudo and Grainger (2000, 2001) and Voga and Giraudo (2009) is often seen as a version of the full listing hypothesis. According to this, word recognition begins with the access of letter information, and morphological and semantic information only becomes available after the lexical representation of a word is accessed. They have named this the Supralexical Model. According to this model, there is an initial stage of whole-word processing followed by a later stage of decomposition in which morphemes receive activation from the whole-word representation. Then, on the one hand, morpheme representations activate the corresponding semantic representations at the semantic level; on the other hand, they send activation back to the holistic lexical representations of all members of the morphological family. That is, the role of morphemes in morphological processing is twofold, since they both mediate the activation of meaning and feed back to the lexical level. In this light, morphological processing is carried out at the interface of form and meaning, guided by the paradigmatic – rather than syntagmatic – relations of morphemes.

In line with a hybrid account of morphological processing, the model proposed by Diependaele (Diependaele et al., 2005, 2009) is a bimodal hierarchical model of word recognition in which morphological effects arise through the interplay of sublexical (morpho-orthographic) and supralexical (morpho-semantic) representations. In other words, their account is similar to a parallel dual-route model, except that it explicitly claims that morphology exerts constraints not only on the structuring of sublexical orthographic representations but also on the structuring of semantic representations. More precisely, they show evidence for the existence of two independent processing systems: one that takes the morpho-orthographic properties of a complex word into consideration and one that takes its morpho-semantic properties into consideration. The former system allows pseudo- *(brothel → broth*) or genuine-root (*brother → broth*) priming to occur whenever a visual prime is fully decomposable into pseudo- or genuine-morphemes, whereas the latter system will produce root priming whenever a visual prime is decomposable into genuine-morphemes and has a semantically transparent relationship with those morphemes (*builder → build*). In this way, the model reconciles the general tenets of the sublexical and supralexical accounts of morphological processing.

2.1.3.2 Models assuming mixed approaches as the starting position

Several early models combining direct access and decomposition exist, and I will briefly mention them. Meys (1975, 1979, 1985) proposed a dual system distinguishing between existing words (Item Familiar Lexicon, IFL), accessed as whole units, and possible words (Type Familiar Lexicon, TFL), constructed using word formation rules. While explaining how novel words might be formed, the model leaves unresolved questions, such as where these rules are stored and how to define the boundary between IFL and TFL. Meys introduces an *activation threshold*, suggesting words become stored in the IFL after frequent use, though the criteria for this threshold are unclear.

Bybee (1985, 1995) addressed the issue of word storage by introducing *lexical strength* (influenced by frequency) and *lexical connections* (reflecting morphological structure). Frequent complex words are stored as whole forms due to strong activation, while less frequent ones are decomposed via morphological links. This model captures the effects of frequency and transparency but lacks detail on how new words are initially processed. Despite limitations, both Meys' and Bybee's models offer valuable concepts – such as IFL/TFL and lexical strength/connections – that have influenced later psycholinguistic theories of lexical processing. Stanners et al. (1979)

proposed a parallel dual-route model, where words like *unstable* activate both the whole form and the root (*stable*), and words with bound roots (e.g. *conceive*) activate related forms (e.g. *receive*, *perceive*). This accounts for affix stripping and the lack of stored bound roots. However, the model focuses only on prefixation, which is relatively unproductive in English, limiting its broader applicability.

All models of lexical access examined so far have had to grapple with the issues of productivity, frequency, transparency, and regularity, which appear to play a crucial role in determining how lexical access is achieved and, consequently, how mental representations are organized. A model such as the Augmented Addressed Morphology (AAM) is a serious attempt to incorporate these factors into its description of the process of lexical access. Inspired by the experimental work of Caramazza and his colleagues (Caramazza et al., 1988; Burani & Caramazza, 1987; Burani et al. 1984; Caramazza et al., 1985; Laudanna et al., 1989; Chialant & Caramazza, 1995) AAM is a typical hybrid model that combines elements of the previous models. In AAM, processing depends on the orthographic surface form. The lexicon is accessed through 'access units', which are either whole words or morphemes. Activation of access units depends on graphemic similarity. For instance, the stimulus *talked* will activate the whole word *talked*, as well as its constituent morphemes *talk* and *-ed.* Moreover, orthographically similar forms such as *walked* and *balked* will also be activated.

One basic assumption of the model is that the system functions in a maximally 'transparent' way.[11] Its main tenet is that lexical access of familiar/frequent morphologically complex words is achieved through whole-word access, while less familiar/frequent but morphologically regular words, as well as new words, are recognized through decomposition (Chialant & Caramazza, 1995). This model incorporates the analytic precision of the decomposition model and the rapidity of the whole-word access model. This makes it a hybrid model that presupposes the existence of hybrid representations for the same word, consisting either of the whole form or its parts.

11 That is, it is assumed that processing relies only on information carried explicitly in the surface form of the stimulus. It follows that in the early stages of processing of an orthographic input stimulus, the system can only make use of the surface orthographic information provided by the isolated stimulus (Chialant & Caramazza, 1995: 63).

Various researchers have pointed out that there are a number of problems with the AAM model. First, Taft (1994) indicates that the AAM makes wrong predictions regarding pseudo-prefixed words, such as *conceive.* Since the model does not allow for the decomposition of such words, their RTs in lexical access should be the same as for non-prefixed words. However, this is not the case, as Taft and Forster (1975) demonstrated increased RTs for pseudo-prefixed words. Another potential problem is that AAM heavily depends on orthographic similarity and overlooks semantic relations and connections. For instance, the model predicts that an irregular past like *went* will activate *wept* (based on orthographic similarity) rather than *go*, which is semantically related. Finally, Frauenfelder and Schreuder (1992) question the 'parallel' character of this model. Since the whole-word representation is always activated faster than the individual morphemes, the decomposition route should be considered as a back-up mechanism, rather than as a process that takes place in parallel. If this is the case, then the AAM model does not differ essentially from the FLH.

As a result of the shortcomings identified in the AAM, Schreuder, Baayen, and colleagues proposed a series of models, culminating in the *meta-model*, which will be examined in the following section. The predecessors of the *meta-model* are Frauenfelder and Schreuder's (1992) Morphological Race Model and Baayen's (1992, 1993) Race Model. In his Race Model, Baayen (1992) points out the crucial role of productivity in accounting for lexical representations. He claims that morphologically productive forms are parsed, whereas unproductive forms are processed through direct access. These two routes start simultaneously as soon as we encounter a word. The route that reaches completion first yields the output. This differs from the AAM model in that it proposes that the two routes may overlap. It is obvious that Baayen links productivity to frequency by assuming that words with productive suffixes are not that frequent, whereas words with unproductive suffixes are usually more frequent. This statement has its problems, since not all low-frequency words can be decomposed to reveal productive affixes.

Frauenfelder and Schreuder (1992) accept most of Baayen's assumptions but also consider other factors that influence parsing. More specifically, while Baayen (1992) only considers frequency as a consequence of productivity, Frauenfelder and Schreuder deal with it as an independent factor. They determine the amount of time required for word recognition along each route. For the direct route, which applies to simple or opaque words, recognition time depends on the token frequency of the word.[12] Words that are frequent will thus be recognized faster. For instance, both *table* and *swamp* will be accessed via the direct route, but *table* will be accessed faster since it is more frequent than *swamp*. In contrast, the recognition time for the parsing route depends on the phonological transparency, the semantic coherence, and the resting activation level of the root and the affix.

For morphologically complex words, the fastest route will depend on the activation levels of the root and affixes relative to the activation level of the whole word. If the word is frequent but phonologically opaque, then the resting activation of the whole word will be greater than the resting activation of its morphemes and, therefore, the direct route will win the race. For instance, while accessing the word *conclusion*, both direct access and the parsing route will be activated. However, since it is a frequent word without clear phonological boundaries,[13] the activation of the whole representation will be greater than the activation of its morphemes, resulting in the direct route for its lexical access. In the case of a low-frequency word, depending on its transparency, the resting activation of its morphemes should be higher than the resting activation of the whole word, giving precedence to the parsing route for its recognition. This is the case for a word such as *unfamiliar*, for which both the whole-word representation and the morphemes will be activated. However, given that the word *unfamiliar* is of relatively low-frequency, the resting activation of its morphemes will be higher than the resting activation of the whole word, and lexical access will take place via parsing. In this way, variables such as transparency, frequency, and productivity are incorporated in the model, and their interaction appears as a crucial condition for the access route and ultimately word recognition. Based on this background argumentation, Schreuder and Baayen (1995) formulated the *meta-model*, which accounts for all these and other factors in considerable detail.

12 Baayen only considered frequency as a consequence of productivity. Frauenfelder and Schreuder deal with frequency as an independent factor.

13 This is because the morpheme boundary affix -*ion* mutilates the stem.

2.1.3.3 Models assuming mixed approaches functioning in parallel (Schreuder & Baayen, 1995)

As I have shown thus far, the dual-route models try to accommodate factors such as frequency, transparency, and productivity in their accounts of morphological processing. The model proposed by Schreuder and Baayen (1995) takes into account an even greater variety of factors, including linguistic ones, and considers how they might interact with each other. The authors aimed to demonstrate the role of meaning during morphological computation. The model tries to incorporate word features ignored by the previous models, which is why it is called a *meta-model.* Apart from the central role of meaning, the meta-model is applicable to all language modalities and can explain morphological processes in a variety of languages.

According to Schreuder and Baayen (1995: 133), morphological processing, whether in production or comprehension includes three stages. The first is *segmentation*, which includes the mapping of the stimulus onto form-based access representations of full, as well as bound forms. The second stage is called *licensing*, and involves checking whether representations that have become active can be integrated on the basis of their subcategorization properties. The third stage, *combination*, deals with the computation of the lexical representation of the complex word from the lexical (syntactic and semantic) representations of its constituents, given that this integration is licensed. A considerable advantage of this model is a mechanism called *activation feedback*, which allows for activation at all levels of the processing mechanism to be affected by all other levels.

Let us examine how this system works when it comes to the recognition of complex words. Schreuder and Baayen (1995: 133) consider that each language has its own 'complex' words, the meaning of which cannot always be inferred from their constituents. For such words, they postulate separate representations at various levels without excluding the fact that fully regular and transparent forms may have their own representations depending on their frequency. The recognition process proceeds in the following way. At the initial stage, the stimulus is transformed into an *intermediate access representation*, which usually contains more than one alternative. For instance, a word like *distraction* might be represented as *distraction* or *distract + ion*. These representations must be mapped onto the *access representation* *proper*. Such 'lexical' access representations may be present for full complex forms, as well as for stems and affixes. Activation speed depends not only on the existing level of activation, but also on the complexity of the mapping process from the intermediate stages to the access representation proper. For instance, when the processor encounters phonological mutations that cause the surface form to differ from the base, a longer processing time will be needed as compared to the time needed for transparent forms. Thus, *destruction* will take longer than *distraction,* due to the change of *destroy* to *destruct-*.

Every access representation is linked to one or more lexical representations. A lexical representation consists of a *concept node*, which is in turn connected to syntactic and semantic representations. For instance, the lexical representation for an inflected form such as *books* should be connected to three conceptual nodes. One node represents the meaning of "book", one represents the meaning of "plural" and one stands for information associated with the grammatical class of "noun". Both the concept nodes and the access representations can receive activation feedback from higher levels. The activation level of a concept node does not depend solely on the access representation, but also on the feedback received from the syntactic and semantic representations, which are very often also activated from other words that have the same syntactic and semantic features.

Once the concept node is activated, the processor has to determine whether the syntactic and semantic representations allow the combination. As soon as the syntactic node gives licensing, the meaning of the complex word has to be computed. At the final stage, the processor has to reach the lexical representation; this consists of a concept node and its associated syntactic and semantic representations. In the case of newly formed words, procedural lexical knowledge is required, since no lexical representation is available. The role of licensing and combination is to create a new representation, which will be linked to syntax through the subcategorization features of the lexical item.

Schreuder and Baayen's (1995) model was the first to take into account linguistic notions such as syntactic subcategorization, and remains the only model which claims that linguistic features are being computed in lexical access. Furthermore, it can account for effects such as root frequency, whole-word frequency, pseudo-affixation, and productivity. More importantly, it gives special attention to the interaction of all of the above-mentioned variables. Despite its strengths, various aspects of the model need further development. For instance, the model positions both the syntactic and semantic representations under the concept nodes, rather than clearly differentiating between the two. Also, although it takes into account syntax and semantics when it comes to representation, it does not mention how the syntactic and semantic features of each word would influence lexical access and how they would interact with the other lexical features.

2.1.4 Other models

Apart from the above-described main psycholinguistic models of lexical access of morphologically complex words, it is important to note that several alternative models were developed concurrently and in recent years, which I will mention in brief here. Among these are *connectionist* models, which question the existence of abstract morphological rules (e.g. Seidenberg & Gonnerman, 2000; Plaut & Gonnerman, 2000). Building on this perspective, a range of learning-based models has emerged. One of the most influential is the Naïve Discriminative Learning (NDL) model (Baayen, 2011; Baayen et al., 2011; Milin et al., 2017), followed by its extension, the Linear Discriminative Learning (LDL) model (Baayen et al., 2019). The Discriminative Learning models predict relatedness effects independent of semantic overlap. In these models, orthographic representations of letter unigrams and bigrams ('cues') are mapped directly onto semantic representations ('outcomes'), such as meanings of words, inflectional meanings, and affixal meanings, without the intervention of form representations of morphemes or whole words (Baayen et al., 2011). These models propose that linguistic categories emerge through learning, driven by the co-occurrence of contextual cues. Central to this framework is the concept of *lexomes*, which represent basic semantic units that point to semantic vectors (Milin et al., 2017). For instance, a derived word would be associated with one lexome for its stem and another for its derivational function, with the semantic vector of the derived word computed as the sum of its component lexome vectors (Chuang et al., 2021).

2.1.5 Interim summary

The foundational question in the study of morphology and the mental lexicon, around which the various models have been formed, is whether words are decomposed, and thus whether they are represented and processed in terms of smaller constituent units. A major divide in the field lies in how different models treat complex words: some assume all complex words are decomposed (Full Decomposition models), others assume no complex word is decomposed (Full Listing models), and some adopt a mixed approach based on specific criteria (Dual-Route models). Each of these models and all together have their own advantages and disadvantages, and ultimately their own truth about morphological processing. Smaldino (2017) claims that models are stupid, but he nonetheless concludes his paper by saying "we need more of them" (Smaldino, 2017: 328).

While all the above models of dealing with the processing of morphologically complex structures provide convenient reference points, the following chapters will bring to light experimental evidence that might speak in favor of or against them. But my aim here is not to compare and evaluate them based on experimental evidence. Instead, what follows will underscore the need to pose more refined questions as a starting point for investigating morphological and lexical representation, free of the obligation of looking for evidence for or against specific models. I aim to clarify this finer-grained set of issues and to go beyond the behavioral adult processing data by incorporating neuroimaging and data from language disorders.

3 Empirical studies on morphological processing: behavioral experiments

In this chapter, I will provide an overview of the main findings on morphological processing based on behavioral studies. I will begin with studies focusing on inflectional morphology, then move on to derivational morphology, and conclude the chapter with an overview of studies on compounding. The presentation of studies is far from exhaustive. Its aim is to highlight factors that affect morphological processing and to sketch the gist of proposals that have been advocated to account for them.

3.1 Studies on the processing of inflectional morphology

The study of *inflectional morphology* in the psycholinguistics of word processing has been a focal point in our understanding of language theory and architecture over the past decades. It offers both challenges and great insights into how humans perceive, store, access, and produce words. The first studies on inflectional morphology mainly focused on languages like English, which has a relatively simple inflectional system. However, the reliance on English has led to certain assumptions about inflectional complexity, regularity, and transparency, which may not be universally applicable when examining more complex inflectional systems, such as those found in Romance, Slavic, Greek, Finno-Ugric, and other languages. These languages present a different picture, where the relationship between these factors is not as straightforward. This challenges traditional views on how inflection operates and raises questions about the division between rules and exceptions, the processing of inflectional forms in real-time versus their storage in long-term memory, and the boundary between morphological processes and lexical representations.

Having said that, one should also keep in mind that while some inflection systems seem to be intuitively more complex than others, this intuition might prove to be tricky (Marzi & Pirrelli, 2022). According to theoretical descriptions, the complexity of an inflectional system is assessed by enumerating the category values instantiated in the system (e.g. person, number, tense, and aspect features) and the range of available markers for their realization. However, this kind of complexity very often fails to differentiate two systems with the same number of possible markers in different paradigmatic combinations. As such, crucial differences might be observed between systems that are equally classified as 'complex'.

For all the above reasons, and when possible, I will make an effort to discuss experimental evidence that goes beyond English. In the following sections, I will review two of the many factors that affect the way we process inflected words, that is, *frequency* and *regularity*.

3.1.1 Frequency effects

The frequency effects associated with the processing of inflected words concern the *frequency of the affix*, the *frequency of the stem*, as well as *surface frequency*[14] and, inevitably, their interaction, which is referred to as *relative frequency*,[15] as well as their interaction with the inflectional system of a specific language.

In general, the frequency of a word in a language plays a crucial role in various aspects of language processing, including word recognition, access, and representation, particularly when dealing with morphologically complex words. One of the most common claims is that word frequency can influence the processing route used for morphologically complex words, determining whether they are processed through decomposition (breaking down into smaller morphemes) or full-form processing (recognizing the word as a whole unit). Pinker (1999) proposed that although regular inflected words are generally processed through the application of inflectional rules, high-frequency regular forms may be directly retrieved from long-term memory as whole lexical units, bypassing rule-based computation. The rationale behind this idea is that high-frequency words are encountered repeatedly in everyday language use, leading to their strengthened neural representations. As a result, they become more readily accessible and recognizable as complete units without the need for rule-based decomposition during processing.

14 The term refers to the frequency of the word as a whole, including the affix, e.g. *agreeable*.

15 *Relative frequency* refers to the relationship between the frequency of morphological constituents compared to the frequency of the whole complex word.

However, it is important to note that the relationship between word frequency and processing route is not absolute, and may vary depending on factors such as language proficiency, individual differences, and contextual cues (Grainger & Beyersmann, 2017; Van Engen et al., 2020). Additionally, the role of frequency in morphological processing is complex and interacts with other factors such as morphological complexity,[16] semantic transparency,[17] and orthographic familiarity.[18] Overall, while the influence of word frequency on morphological processing routes is a compelling area of research, it is just one piece of the larger puzzle of language processing. Empirical investigations have clearly shown this, and they have fully elucidated the intricate interplay among frequency, morphological structure, and cognitive mechanisms involved in language comprehension and production. Their detailed description, however, is beyond the scope of the current chapter.

The research findings I will review highlight the influence of word frequency on the processing of morphologically complex words and suggest that the threshold for full-form processing may vary across languages due to differences in morphological structure and richness. In a study by Alegre and Gordon (1999), which focused on adult monolingual English speakers, they found evidence that full-form representations start to develop for morphologically complex words when the *surface frequency* of the word exceeds six occurrences per million. This suggests that for English speakers, relatively low frequencies are sufficient to trigger full-form processing for certain inflected words. On the other hand, Lehtonen and Laine (2003) examined this phenomenon in speakers of Finnish, a language with a highly complex morphological system. They found that adult Finnish monolinguals developed full-form representations for high-frequency

16 The notion of *morphological complexity* is explained in the Introduction.

17 [3] *Semantic transparency* refers to how the meaning of a complex word can be understood based on the meanings of its individual parts, such as morphemes or constituents. A detailed description can be found in § 3.2.2.

18 *Orthographic familiarity* refers to the extent to which a word's spelling conforms to common and frequently encountered letter patterns in a given language. It reflects the reader's experience with similar orthographic forms and contributes to the ease and speed of word recognition (Balota et al., 1991). Importantly, orthographic familiarity is distinct from word frequency: a word can be low-frequency yet orthographically familiar if it shares structure with other frequent words (e.g. *glade* resembles *blade*, *grade*), and conversely, high-frequency words may sometimes have unusual orthographic patterns (e.g. *awkward*).

inflections when the surface frequency of the word reached about 100 per million. This suggests that in languages with rich morphological systems, like Finnish, a higher frequency threshold may be required for full-form processing to occur, further implying that the structure and morphological richness of the language determine the limit for full-form processing. Thus, the complexity and diversity of morphological forms in a language can influence the cognitive mechanisms involved in word processing. An interesting set of data comes from Swedish. While earlier studies (Ahlsén, 1994; Portin & Laine, 2001) found that inflected forms were processed as full forms, Lehtonen et al. (2007) found that Swedish inflected words are subject to decomposition when they are of low frequency. Medium- and high-frequency inflected words, in turn, appear to be processed as full forms (Lehtonen et al., 2007).

Finally, Marzi and Pirelli (2022) provide a nice overview of Romance inflected words, and they show that *surface* but also *stem* frequency effects are systematically observed in Italian (Burani et al., 1984) and French inflection (Colé et al., 1989).[19] *Surface* and *stem* frequency effects are also found in experiments adopting a factorial design, that is, modeling frequency as a two-level variable – high vs low (Taft, 1979; Taft & Ardasinski, 2006). This is confirmed in a series of languages (e.g. Italian: Burani et al., 1984; French: Colé et al., 1989; Dutch: Baayen et al., 1997; Finnish: Lehtonen et al., 2007). An interesting point which is brought up by Amenta and Crepaldi (2012) is that *stem* frequency effects can only be accurately examined when surface frequency is controlled, typically by matching this variable across high- and low-frequency stem words. However, as Amenta and Crepaldi (2012) point out, this methodological constraint led researchers to overlook, for many years, the possibility that stem frequency effects might in fact be modulated by surface frequency. This issue was examined by Baayen et al. (2007), who initially found no stem frequency effects in an experiment that included only low-frequency words – specifically, prefixed and suffixed derivations and suffixed inflections (e.g. *aback, boarder, absences*). However, in a subsequent experiment that encompassed a broader range of target words (a total of 8,486 morphologically complex words) varying in

19 In Colé et al. (1989) the cumulative stem frequency effect on lexical decision times was found only in the case of suffixed words, but not in prefixed words. This was explained in terms of more effortful morphological decomposition of prefixed words as compared to suffixed words.

both whole-word and stem frequency, stem frequency appeared as a significant predictor, although its effect was modulated by whole-word frequency. In other words, stem frequency facilitated processing (the participants were faster and more accurate) for low-frequency words, but they were slower or less accurate for high-frequency words, showing an inhibitory effect. Based on this finding, the authors concluded that surface frequency must be the most important predictor, with only a marginal role for stem frequency.

In sum, there is robust evidence that stem frequency affects the identification times of complex words independently of affix properties such as frequency and productivity. Additionally, there is evidence that the stem frequency effect interacts with surface frequency, facilitating processing for low-frequency words while inhibiting it for high-frequency ones. Overall, these studies highlight the intricate relationship between word frequency, morphological complexity, and processing strategies in different languages. They emphasize the importance of considering language-specific factors when studying cognitive processes such as word recognition and access. Further research exploring how linguistic properties interact with cognitive mechanisms will contribute to a deeper understanding of language processing across diverse linguistic contexts.

3.1.2 Regularity effects

Regularity in inflectional paradigms refers to the consistency with which morphological rules apply to word forms within a language. In inflectional paradigms, different forms of a word (e.g. forms that denote tense, number, case, etc.) follow specific patterns that may either be *regular* (consistent and predictable) or *irregular* (deviating from the standard pattern). The more transparent the relations between fully inflected word forms are, the less complex a paradigm is taken to be. Accordingly, the amount of uncertainty in inferring an inflected form from another form (or from a set of paradigmatically related forms) provides a measure of the complexity of a paradigm, and, ultimately, of an entire inflection system.

We encounter some common examples of regular and irregular forms in the formation of the English past tense. Consider the difference between *go – went* and *talk – talked*, with the former pair being considered irregular and the latter pair being considered regular formation of the past tense. This is known in the literature on language processing as the *past-tense debate.*[20] It refers to the long-standing controversy in psycholinguistics and cognitive science about how we process the past tense of verbs, especially the difference between regulars and irregulars. While the above constitutes a clear case and a dichotomy between the two, stem allomorphy (*sing – sang*, *drink – drank*) makes inter-predictability relations more complex. Occasionally, it may be difficult to predict what formal change a stem allomorph undergoes and where in the paradigm. Moreover, regardless of their complexity or irregularity, inflectional systems are structured so that less predictable forms tend to occur more frequently than more predictable ones, highlighting the intricate relationship between regularity and frequency.

Regular forms show strong frequency effects. High-frequency regular forms are processed more efficiently due to repeated exposure and stronger mental representations (Bybee, 1995). Irregular forms also exhibit frequency effects, though the patterns can differ. High-frequency irregular forms are often retrieved as whole units from memory (Pinker, 1991), while low-frequency irregulars might be more difficult to retrieve, leading to slower processing or even errors (e.g. producing *sinked* instead of *sank* under pressure).

Marzi and Pirelli (2022) claim that regularity in Romance languages is different from regularity in English. Both regular and irregular Romance inflections show some combinatorial structure, apparently requiring composition and decomposition of stems and affixes. Affixation is not exclusive to regular inflection but represents just one of several strategies for marking morphosyntactic contrasts. Accordingly, irregular forms in the Romance languages are not inherently phonologically simpler than their regular counterparts. In this respect, Romance irregular stem formation may be compatible with combinatorial, regular inflection, and thus susceptible to the same type of processing. Indeed, evidence from a visual LDT demonstrates robust stem frequency effects for both regular and irregular French verb inflection (Estivalet & Meunier, 2015) with irregular verbs accessed

20 Pinker (1999) first coined and crystallized the discussion under the label *past-tense debate.* The foundations of the debate are built on: a) Chomsky (1965) who introduced the idea of an innate rule-based system underlying language; b) Pinker (1999) who presented the argument that regular morphological forms are generated by rules, while irregulars are memorized; and c) Ullman (2001) who proposed two memory systems: declarative (lexicon/irregulars) and procedural (grammar/regulars).

via distinct allomorphic stems (e.g. *boi-* and *buv-* for *boire* 'to drink'), in the same way as regular ones.

Important insights come from studies on inflectional morphology in Greek,[21] further highlighting the role of specific inflectional systems in the processing of inflectional morphology, but also the role of the experimental stimulus set. The studies discussed below employ the *morphological priming paradigm*[22] and engage with various theoretical models concerning the representation and processing of morphologically complex words. Verbal inflection was a central focus in a *masked priming*[23] study by Voga and Grainger (2004), which examined the role of morphological similarity, in pairs such as *epeksa* → *pezo* 'I played' → 'I play' (low similarity) vs *filaksa* → *filao* 'I saved → I save' (high similarity). Their results showed that morphological similarity influenced priming only when unrelated controls were used (e.g. *valo* → *pezo* 'I throw → I play'), but not when form controls were included (e.g. *pera* → *pezo* 'beyond → I play'). From this, they concluded that masked morphological priming is largely independent of surface similarity and instead taps into abstract morphological representations of inflectional morphology.

Anastasiadis-Symeonidis and Voga (2012) also investigated verbal inflection (present/past tense) using a masked priming paradigm. Their findings revealed that present tense forms prime other present tense forms across conjugation classes. However, past-tense forms only prime present tense form in the *-ω (-o),* e.g. *lyno* 'tie' (first conjugation class) and *-άω (-áo)*, e.g. *foráo* 'I wear' (second conjugation class) conjugation types, but not those in the *-ώ (-ó)* type, e.g. *foró* 'I wear' (alternative type of second conjugation class). They interpreted this pattern as evidence that the alternative type (*-ώ* (*-ó*)) and basic forms (*-άω* (*-áo*)) of the second conjugation occupy distinct morphological positions. Even though no information is provided

21 For details see Soukalopoulou (2023) and also Ntagkas (2023).

22 Priming is an experimental technique used in psycholinguistics and cognitive neuroscience to investigate how exposure to one stimulus (the prime) influences the processing of a subsequent stimulus (the target). In the context of language processing, priming reveals the mental representations and mechanisms involved in accessing words, morphemes, or meanings.

23 Masked priming is a priming technique that combines a very short prime presentation (in the range of 25–50 ms) that is immediately followed (and often preceded) by a meaningless character string such as "######". Masked priming reduces strategic processing (Forster & Davis, 1984), and, most importantly, it can entirely suppress semantic priming, making it the ideal technique for investigating formal and morphological effects independently of semantics.

by the authors about the frequency of occurrence of each conjugation class, the finding highlights individual differences in the processing of inflectional morphemes performing exactly the same operation.

Extending this line of inquiry, Soukalopoulou (2021) examined present and past tense verbal inflection in Greek, distinguishing three categories of past-tense formation: (i) regular forms with the affix -σ-/-s- (e.g. *lyno* → *elysa* 'I tie → I tied'), (ii) irregular forms with unpredictable stem changes (e.g. *pigeno* → *piga* 'I go → I went'), and (iii) mixed forms with both stem change and affixation (e.g. *roto* → *rotisa* 'I ask → I asked'). Using a *cross-modal priming*[24] design, she found comparable priming effects across all categories, suggesting a shared mechanism of morphological decomposition and common underlying representations for perfective verb forms, independently of regularity. This result was interpreted as support for the decomposition model (see Chapter 2, § 2.1.1).

Important insights also come from Tsapkini et al. (2002, 2004), who studied various degrees of regularity in both verbal (present/past) and nominal (singular/plural) inflection using masked, overt, and cross-modal priming paradigms. Their findings indicated that inflectional regularity effects were influenced by modality (visual vs auditory), stimulus presentation duration (35 ms vs 150 ms), and grammatical category (verbs vs nouns). They proposed a two-stage model of morphological processing, where initial access is modality-dependent, but deeper morphological representations are modality-independent. Crucially, they argued against treating morphological regularity as a binary distinction, emphasizing that structural effects emerge later at the deep representational level.

3.1.3 Interim summary

The above provides a quick glimpse into some of the issues related to the processing of inflectional morphology. It is evident that research on the processing of inflectional morphology has focused mainly on verbal morphology and the distinction between present and past tense. Overall, research supports an interactive, language-sensitive model of morphological

24 The cross-modal priming paradigm involves presenting a prime in one modality (e.g. auditory) and a target in another (e.g. visual) to examine how the processing of the prime influences the response to the target.

processing, where frequency, regularity, and complexity dynamically shape processing routes. Frequency effects influence the processing of inflected words, involving stem frequency, affix frequency, and surface frequency, which interact with language-specific inflectional systems. High-frequency words are more likely to be processed as whole forms due to stronger mental representations, while low-frequency words often undergo morphological decomposition. Regularity effects refer to how predictably inflectional rules apply. Both regular and irregular forms show frequency sensitivity, but may rely on different processing mechanisms. When one goes beyond English, regularity spans in a continuum from regular to semi-regular and irregular forms, giving rise to a variety of interpretations with respect to their processing routes. The findings of the reviewed studies were interpreted either as evidence for full decomposition or as evidence of dual-route models of lexical access.

3.2 Studies on the processing of derivational morphology

One of the main questions that has occupied research on the processing of derivational morphology is whether morphologically complex words are processed as whole items, as suggested by the FLH (§ 2.1.2), or whether they are decomposed into smaller units, as suggested by the full decomposition model (§ 2.1.1). This question has occupied the literature for decades, in parallel with questions regarding inflectional morphology. To this end, several researchers conducted visual LDTs by using mainly the priming paradigm. The main finding of these experiments was that when a morphologically complex word, like *teacher*, was used as a prime, it facilitated the recognition of its base (*teach*) or another morphologically related word, like *teaching*, in comparison to an unrelated prime, like *play*. According to the FLH, the priming effect can be explained by the spreading of activation from the complex word to the base or to related complex words through links between their lexical representation. In contrast, the decomposition models suggest that the priming effect can be explained by a direct activation of the stem, which is extracted during the decomposition process.

Longtin and Meunier (2005) conducted a priming LDT aiming to investigate these two aspects of processing by manipulating complex pseudowords in French. The rationale behind using complex pseudowords is that they are interpretable, albeit non-existent, but they can only be processed by being analyzed into smaller units. This means that if morphological priming effects can be explained through whole word representation and subsequent spreading activation from the complex word to its base, then the pseudoword **quickify* cannot prime its base *quick* because the search for the whole word representation of **quickify* would not be successful. On the other hand, if morphological priming effects are due to the activation of the stem through morphological decomposition of the pseudoword, then morphologically complex pseudowords should prime their stem as successfully as existing derived words do. The researchers used the following types of primes: a) semantically interpretable pseudowords made from a grammatical combination of stem and suffix (e.g.**rapidifier* → *rapide* 'quick'+ *-ifier* '-ify', b) non-morphological pseudowords in which the ending of the word is not a suffix (**rapiduit* – *rapide* + *-uit*), c) non-interpretable combinations of stem and suffix (**sportation* – *sport* + *-ation* (the suffix *-ation* only attaches to verbs not nouns), and e) existing suffixed words (e.g. *rapidement* – *rapide* + *-ment*). The results showed facilitated recognition of the stem when primed by a semantically interpretable grammatical pseudoword (e.g. **rapidifier* '*quickify'→ RAPIDE 'quick'), with the priming effect being equal to the one observed when the prime word was an existing derived word (*rapidement* 'quickly' → RAPIDE 'quick'). This was the case even when the prime word was a non-interpretable formation (e.g. **sportation* → SPORT). Similar effects did not arise when primes were pseudowords consisting of a stem and a non-morphological ending (e.g. *rapiduit* → RAPIDE), meaning that the facilitation observed for morphologically structured pseudowords was not the result of simple orthographic overlap, but of decomposition of the pseudoword into smaller units that represent a base and a suffix. These findings provided support to the full decomposition model and indicated that morphological decomposition applies to all morphologically complex structured stimuli, irrespective of whether they are existent words or not. If this were not the case, then complex pseudowords would not have facilitated the recognition of their stems. The overwhelming majority of experimental research investigating morphological decomposition focuses on suffixation (and to a lesser extent on prefixation) in Indo-European languages, where affixes can be easily located at the edge of the stem (Rastle & Davis, 2008 for a review). Specifically, such effects have been reported in several languages such as Spanish (e.g. Sánchez-Casas et al., 2003), German, Dutch (e.g. Drews & Zwitserlood, 1995), Hebrew (e.g. Frost et al., 1997), and English (Rastle et al., 2004).

In the debate between whole-word access vs full decomposition, the role of variables such as frequency, productivity, and regularity appear to play a role, and this will be discussed in the following sections.

3.2.1 Frequency, family size, and length effects

Similarly to inflectional morphology, factors such as *frequency* play a decisive role in determining whether derived words are decomposed during lexical access. Numerous studies have shown that access to morphological constituents is influenced by the external properties of morphologically complex words. In derivational morphology studies, a key term to consider is *relative frequency* (see § 3.1.1), which can have a significant impact. For instance, evidence supporting reliance on morphological structure in accessing printed complex words comes from studies on low-frequency words with higher-frequency constituents (e.g. Andrews 1986; Burani & Caramazza 1987; Meunier & Segui 1999). Similarly, dual-route models of lexical access (see § 2.2.1.3) propose that words with multiple morphemes activate two types of access units in parallel – those corresponding to the whole word and those corresponding to its morphemes. In these models, the relative frequency of the whole word and its constituent morphemes influences the activation timing of the different units. As a result, frequency becomes the primary determinant of whether lexical access favors whole-word or morpheme-based processing.

These models are based on the assumption that the higher the frequency of a lexical unit, whether it is a word, root, or affix, the more likely it is to be quickly activated and processed across different components. Crucially, the probability that lexical access is driven by either whole-word or morpheme processing depends on the complex balance between the frequency of the entire word and the frequency of its constituent morphemes, including both roots and affixes. In other words, it is *relative* frequency rather than absolute frequency that matters (see Hay 2000; 2001 for a discussion).

Bradley's (1979) study showed a stem frequency effect only for derived words with productive endings like *-ness* or *-ment*, while derived words with less productive affixes showed only a surface frequency effect. Burani and Thornton (2003) studied the effects of stem and affix frequency on RTs in LDTs involving both derived words and pseudowords in Italian. They found that RTs depend on the interaction between stem and affix frequency. Specifically, suffixed pseudowords with higher-frequency affixes (e.g.**prucezza*, **feldismo*) led to longer decision latencies and higher error rates compared to those with lower-frequency affixes (**gurnense*, **cettoide*). Additionally, they observed an asymmetrical pattern for high- and low-frequency stems: high-frequency roots (e.g. *bassezza* 'baseness') resulted in faster and more accurate responses, while low-frequency roots (e.g. *rudezza* 'rudeness') showed no advantage over non-derived words (e.g. *avezzo* 'accustomed'), regardless of affix frequency. The findings suggest that *stem frequency* is the primary factor influencing lexical decision performance, with affix frequency playing only a marginal role.

On the opposite side, extensive research has demonstrated that *suffix frequency* plays a significant role in visual lexical recognition. For example, Baayen et al. (2007) found in an unprimed LDT in English that both surface frequency and suffix frequency – measured as token frequency – predicted response latencies. Adults were more influenced by high-frequency suffixes than by low-frequency ones. Baayen et al. (2007) suggested that suffix frequency reflects the strength of stored morphological units in the lexicon and the likelihood of these units enhancing lexical retrieval (see also Anshen & Aronoff, 1997; Bertram et al., 2000b; Frauenfelder & Schreuder, 1991; Hay, 2001).

Morphological family size effects, referring to the number of words sharing the same stem, have consistently been found in LDTs (Balling & Baayen, 2008; Bertram et al., 2000a; De Jong et al., 2000; Ford et al., 2010; Moscoso del Prado Martín et al., 2004). This suggests that words from larger morphological families are easier to access than those from smaller families, as the stem is more easily accessed through a broader network of related words.

Another key aspect of morphological family size effects is their modulation by the relative frequency of a word compared to other family members (Colé et al., 1989; Meunier & Segui, 1999). Meunier and Segui (1999) compared LDT RTs for complex words with many high-frequency family members to those with fewer high-frequency competitors. They found that words with fewer high-frequency competitors were recognized significantly faster. This suggests that when all family members are activated, access to the target word is easier if it faces less competition from higher-frequency family members. This effect has been observed in both auditory (Meunier & Segui, 1999) and written (Colé et al., 1989) modalities.

While the various types of frequencies have been extensively studied, *affix length* (i.e., the number of letters in an affix) has received less attention. However, affix length effects are more consistent across studies compared to frequency effects, which often show inconsistencies. Laudanna and Burani (1995) proposed that words with more salient affixes, such as longer ones, are more likely to be decomposed into morphemes than those with less salient affixes. Longer affixes are visually more noticeable, increasing their salience. Kuperman et al. (2010) confirmed this, showing that whole-word frequency effects are less pronounced in words with longer suffixes, indicating that affix length is a critical variable in studies exploring the interaction between whole-word and morphemic factors in word processing.

3.2.2 Transparency effects

When examining the effects of transparency on the recognition and representation of derived words, it is important to clarify that I refer to two distinct types of relations between stem and affix. The first could be described as *morphological transparency*, and the second as *semantic transparency*. An example of a morphologically transparent word would be *player* and an example of a morphologically opaque word would be *corner*. Morphologically opaque words are usually described in the literature as *pseudo-derived,* and they refer to all these formations that contain an affix-like string, such as *-er* in *corner*. Semantically opaque derived words, on the other hand, include forms such as *understand*, *department*, etc. These words are morphologically derived but have no relation to their stems. In the remainder of the section, I will discuss the effects of morphological transparency and semantic transparency separately.

Quite a few masked priming studies using both morphologically transparent and opaque (pseudo-derived) words (e.g. Beyersmann et al., 2016;

Diependaele et al., 2009, 2005; Longtin et al., 2003; Marslen-Wilson et al., 2008; McCormick et al., 2008; Rastle et al., 2000; Rastle & Davis, 2003; Rastle et al., 2004) have shown significant priming for both *player* → *play* and *corner* → *corn*, suggesting the existence of a semantically blind mechanism of pre-lexical morpho-orthographic decomposition. Similar effects were not found for *brothel* → *broth*, indicating that decomposition operates strictly on a morpheme level and not on orthographic overlap. A different group of studies (Feldman et al., 2009, 2015; Andrews & Lo, 2013) has shown that semantically transparent pairs (*player* → *play*) are in fact faster than pseudo-derived pairs such as *corner* → *corn*, challenging the form-first accounts. Similarly, Milin et al. (2017) showed that *corner* → *corn* pairs elicited equal effects to orthographically related pairs such as *cornea* → *corn*. These results support the view of simultaneous access of form and meaning during recognition of derived words. Taking these two separate lines of research together, it seems that the evidence on the role of morphological transparency is highly contradictory.

Studies that compare semantically transparent (*underestimate*) to semantically opaque derived words (*understand*) usually employ the overt priming technique, where primes are consciously perceived. Cross-linguistic experimental results suggest a discrepancy depending on the specific language. For instance, for English and French, semantically transparent primes facilitate target processing in overt priming, opaque primes show facilitation only at short SOAs[25] (Rastle et al., 2000). Similarly, and for these two languages, priming effects have been reported for semantically transparent pairs but not for opaque ones in cross-modal priming studies (Feldman et al., 2004; Gonnerman et al., 2007; Longtin et al., 2003; Marslen-Wilson et al., 1994), with findings extending to Serbian, too (Feldman et al., 2002). However, when one looks at Semitic languages with non-concatenative morphology, both semantically transparent and semantically opaque words show robust morphological priming (see for Arabic: Boudelaa & Marslen-Wilson, 2004, 2005, 2015; for Maltese: Ussishkin et al., 2015; for Hebrew: Frost et al., 1997; Feldman & Bentin, 1994). German prefixed verbs elicited the same pattern of equal magnitude priming for semantically transparent and opaque derived words (Smolka et al., 2009, 2014, 2015,

25 Stimulus Onset Asynchrony (SOA) refers to the time interval between the onset of a prime stimulus and the onset of a subsequent target stimulus.

2019) compared to unrelated pairs. Yet, a more recent study employing auditory-auditory primed LDT found that semantically opaque prefixed words in Dutch produce morphological priming effects (Creemers et al., 2020). The participants performed lexical decisions on stems such as *bieden* 'offer', presented after semantically transparent prefixed primes (e.g. *aanbieden* 'offer') and opaque primes (e.g. *verbieden* 'forbid') among other control conditions. The results show robust facilitation for both transparent and opaque pairs. The finding of facilitation with semantic opaque primes suggests that morphological processing is independent of semantic and phonological representations. These results challenge theories that require semantic overlap as a prerequisite for morphological relatedness. Instead, they support approaches that allow words to be related through mechanisms independent of shared meaning, such as the full decomposition approach and the Discriminative Learning models (see § 2.1.4).

To conclude, the study of transparency effects in the word recognition and representation of derived words has produced contradictory results. In all cases, real morphological effects have been found for transparent cases, but for morphologically opaque and semantically opaque derived words, the results differ depending on language, task, and experimental settings. I will come back to this in the Neuroimaging section (Chapter 4).

3.2.3 The case of deverbal nominals

The processing of deverbal nominals (nouns and adjectives deriving from verbs) has a special place in the literature on derivational morphology. The work of Manouilidou and her colleagues (Manouilidou, 2006, 2007; Manouilidou et al., 2009; Manouilidou & Stockall, 2014; Tsaprouni, 2019; Tsaprouni & Manouilidou, 2021, 2025) on the deverbal derivatives of Greek is rich, with emphasis on the processing of verbal features, such as argument structure and aspect, which may be carried over by the deverbal formations.

Specifically, in the first study of this line of investigation, Manouilidou (2006) addressed two independent issues with respect to the *thematic features*[26] of deverbal nominals. The first question was whether the processing

26 The term *thematic features* is used by Manouilidou (2006) to denote the verb-related properties of a deverbal nominal. These refer to properties that allow the deverbal derivatives to receive

of thematic features constitutes a necessary step in accessing their mental representation. The second concerned the status of thematic constraints in deverbal word formation. Three online LDTs and one offline grammaticality judgment task were carried out. The stimuli for these tasks included several types of deverbal nouns (*plysimo* 'washing', *kataktitis* 'conqueror'), several types of deverbal adjectives (*kallymenos* 'covered'), pseudowords violating thematic constraints (**orimastis* 'maturer'), and pseudowords violations categorial constraints of the base (**kareklatis* 'chairer'). The findings showed that thematic features appear to increase processing load only for a subset of deverbal nominals and more specifically for those with an increased eventive character (e.g. *plysimo* 'washing', *kallymenos* 'covered'). In contrast, thematic features do not appear to affect processing in the case of deverbal nominals with a diminished 'verb-like' character (e.g. *kataktitis* 'conqueror', *vrastos* 'boiled') (see Manouilidou, 2006 for a discussion). Furthermore, increased RTs for pseudowords such as **orimastis* 'maturer'[27] violating the argument structure specifications (also classified as belonging to *thematic features*) of the base verb *orimazo* 'to mature' indicated that thematic features impose constraints which operate at a later stage of word formation compared to other constraints, such as categorial specifications of the base, as examined through pseudowords of the type *kareklatis* 'chairer'. This strongly suggests that thematic features play a crucial role in the creation of new deverbal nominals, independently of the type of nominal. Manouilidou (2006) further discussed the psycholinguistic and linguistic implications of these experiments, which support the stage-like nature of lexical access, and the existence of a general representational component called *feature representation* (Manouilidou, 2006: 171-172), also highlighting the role of grammatical class in both lexical access and the organization of the lexicon.

This line of research, particularly the pseudoword design, was further developed and expanded to include other languages, such as English, Slovenian, and more recently, Bosnian-Croatian-Montenegrin-Serbian (BCMS), with considerable contributions to the investigation of post-decomposition

verb-related syntactic complements, e.g. "of the city" in the phrase *the destruction of the city*, and to receive verb-related modifications, e.g. *by the enemy* in the phrase *the destruction of the city by the enemy*.

27 In this type of violation, unaccusative verbs (e.g. *orimazo* 'to mature') were used, which are specified for internal theme arguments together with the suffix *-tis* '-er', which needs an agentive verb.

processes, within the model of Schreuder and Baayen (1995) (see § 2.2.1.3.2). Specifically, Manouilidou and Stockall (2014), in parallel to Greek, also investigated English formations with the prefix *re-*, of the type **rehappy* which violates the grammatical category rule of [*re-* + verb], and of the type **resmile*, which violates the argument structure specifications of the verbal stem [*re-*+ unaccusative verb].[28] The results of LDTs and grammaticality judgments showed similar patterns in participants' performance in both Greek and English, despite the typological differences between these two languages and independently from suffixation (Greek) vs prefixation (English). Specifically, acceptability judgment scores revealed that speakers rejected the majority of both types of violations, yet they accepted significantly more thematic violations compared to categorial ones, a pattern which was replicated by the acceptance rates from the LDT. With regard to RTs, the participants took longer to respond to argument structure violations compared to categorial violations in both Greek and English word formations. The authors (Manouilidou & Stockall, 2014) suggested that their data provide support for decomposition and a stage-like process for lexical access.

More recently, this work has been extended to include data from South Slavic languages, such as Slovenian and BCMS, adopting at the same time the terminology put forward by Schreuder & Baayen (1995) to describe the stage-like process of lexical access of complex words. Specifically, Marjanovič et al. (2013) and Manouilidou et al. (2016) created pseudowords with the Slovenian suffix *-ec* (the semantic equivalent of *-er* in English), which violated either the grammatical category of the stem (**čokoladilec* 'chocolater') or the argument structure of the verbal stem (**umiralec* 'dier'). Moreover, they introduced an extra type of violations, called *aspectual violations,* in which there was a mismatch between the aspectual requirements of the specific suffix (imperfective) and the aspectual specifications of the verbal stem (perfective). This led to formations such as **preplavalec* (from the perfective verbal base *preplavati* 'to swim through'). Slovenian young participants in Marjanovič et al. (2013) robustly rejected all types of pseudowords with violations, making no distinction among them. However, 21 older adults (aged between 60–79, mean: 67.8) as investigated in

28 Specifically, the prefix *re-* requires an internal, affected argument, and it was paired with unergative verbs such as *smile,* which do not take internal arguments.

Manouilidou et al. (2016) differentiated among all types of violations in both the grammaticality judgment task and the LDT. Namely, aspectual violations yielded higher error rates and slower RTs, suggesting that the processing of aspect was part of the recognition process of these pseudowords.

Aspect was later investigated by Tsaprouni & Manouilidou (2025) in Greek deverbal nominals with a variety of suffixes by using both grammaticality judgments and LDTs. This experiment yielded contradictory results, suggesting that the processing of aspect depends on the specific suffix. For instance, processing of the functional category of aspect was detected for the suffix -*simos* (-*able*), which creates formations with unambiguous, eventive readings and which has clear event implications, but not for formations with the suffixes -*menos* and -*tos*[29] which fluctuate between formations with eventive and non-eventive readings.

Tsaprouni & Manouilidou (2021) also investigated whether Greek native speakers are able to distinguish between different stem types used for the formation of deverbal adjectives. To this end, they examined the whole spectrum of possible unattested combinations by using a variety of verbal stems in an offline acceptability judgment task. For example, while in all other studies following this line of research, there was homogeneity in the creation of their argument structure violations, all being based on a specific type of verbs, i.e. unaccusatives, Tsaprouni & Manouilidou (2021) experimented with the contribution of each verb type in the creation of violations. For example, they had the suffix -*simos* (-*able*) attached to unergative verbs *trek-simos* 'run-able', to subject-experiencer psychological verbs *misi-simos* 'hate-able', to causative verbs *skoto-simos* 'kill-able'. This variety of combinations aimed to point out fine distinctions among verb types and, at the same time, to highlight the distinct interactions each suffix has with each type of verbal stem. Indeed, native speakers distinguish between distinct verbal stems, and therefore between their separate argument structures, bringing into light a gradient violability not only between distinct types of

29 The three suffixes share similarities and differences. The suffix -*simos* denotes 'possibility/ability' and it always involves an Agent and a Theme event participants. The suffix -*menos* can create adjectives that denote a 'result state', e.g. *skotomenos* 'killed', and it can also create adjectives that denote a "target state" which are in principle reversible, e.g. *krimenos* 'hidden'. Finally, the suffix -*tos* has two interpretations, one denoting 'ability/possibility', in examples such as *fouskotos* 'inflatable', and one denoting 'characteristic state', such as in *vrastos* 'boiled'.

violations, namely categorial and argument structure, but also among the distinct types of verbal stems.

Finally, Ristić et al. (2025) added a purely semantic dimension to 'thematic violations' as they based them on a more unambiguously semantic restriction of *state stability*, by focusing on prefixes *raz-*, *od-*, and *vz-/uz-* in Slovenian and BCMS. None of these prefixes attaches to stable state verbs, i.e., *to dwell.* In two acceptability judgment tasks and two LDTs, one for each language, they showed that semantic violations (*raz-'dwell'*) were consistently more acceptable, rejected more slowly and less accurately than category selection violations (*raz-'mother'*), across prefixes and languages. This added evidence for the distinction between the two post-decomposition stages from a new semantic dimension and spoke to the universality of this distinction in lexical processing.

The contribution of this line of research is crucial in informing theories of lexical access based on linguistically informed approaches, and it will be further discussed in Chapter 4 together with the neuroimaging data that has emerged in parallel with the behavioral investigations.

3.2.4 Interim summary

The section was dedicated to the investigation of the processing of derived words. A key experimental method for examining this is the priming paradigm in LDTs, and a key type of stimuli is pseudowords. Evidence across multiple languages (e.g. English, French, Hebrew, Spanish) indicated the prevalence of decomposition as access route, especially in affix-rich Indo-European languages. Studies showed that even non-existent yet grammatically plausible pseudowords (e.g. **rapidifier*) facilitate recognition of their base forms, indicating that decomposition mechanisms operate independently of lexical status, supporting the decomposition view.

The role of *frequency, morphological family size,* and *affix length* significantly affects morphological processing. Studies show that *relative* frequency, that is, how frequent a stem or affix is compared to the whole word, determines whether processing favors the morpheme or whole-word route. High stem frequency improves recognition, and suffix frequency also contributes, although its influence is debated. Additionally, *morphological family* *size* (number of words sharing a root) and *affix length* influence the ease of access, with longer and more salient affixes aiding decomposition.

The section also examines *transparency effects*, differentiating between *morphological* (form-based) and *semantic* (meaning-based) transparency. While early studies showed that morpho-orthographic decomposition can occur even in semantically opaque pairs (e.g. *corner* → *corn*), newer research suggests that semantic transparency facilitates faster and more robust priming, implying simultaneous access to both form and meaning. Cross-linguistic variations emerge; in languages with non-concatenative morphology (e.g. Arabic, Hebrew), both transparent and opaque forms show strong priming effects, unlike in English and French where opaque forms often show reduced effects.

Finally, the case of *deverbal nominals* – nouns and adjectives derived from verbs – offers insights into post-decomposition processes. Research by Manouilidou and colleagues using Greek, English, Slovenian, and other South Slavic languages reveals that processing of thematic, categorial, and aspectual features of the verbal stem affects recognition of derived nominals. Violations of argument structure or aspect in pseudowords (e.g. **resmile*, **umiralec* '*dier') led to slower RTs and higher error rates, especially in older participants. These findings support a stage-like model of lexical access and underline the importance of grammatical features in morphological processing.

Overall, the evidence supports models that allow for flexible, dynamic processing of derivational morphology, with decomposition playing a central role influenced by frequency, transparency, and morphosyntactic constraints.

3.3 Studies on the processing of compounding

One of the most intriguing aspects of compound word processing lies in their dual nature. Unlike inflected or derived words, compounds are formed by combining two existing lexemes (e.g. *doll* + *house* = *dollhouse*), rather than through affixation or inflection (Libben, 2006). This morphological structure allows compounds to be represented either holistically, akin to simple words like *table*, or through the decomposition of their constituent morphemes, or potentially both (Libben et al., 2020). Consequently, compound words provide a unique domain for examining the mental representation and access of complex words, offering insights into how morphological and semantic structures interact during lexical access (Leminen et al., 2019; Libben et al., 2020 for reviews).

Over the past thirty years, various methodologies, ranging from behavioral to neuroimaging approaches, have been employed to investigate compound processing. Among these, LDTs have been especially informative. Early influential work by Taft & Forster (1976) was the first to deal with the representation of compounds by using online methods. They employed lexical decision experiments using nonwords such as **mowdflisk* (nonword-nonword), **dustworth* (word-word), and **footmilge* (word-nonword). Their findings revealed faster rejection of pseudo-compounds when the first constituent was a nonword, suggesting a pre-lexical morphological parsing process and highlighting the primacy of the initial constituent in lexical access, a key tenet of full decomposition models.

Subsequent studies have nuanced this picture by demonstrating that both constituents may be accessed during compound recognition, and not just the first one. Lexical decision experiments employing constituent priming paradigms (e.g. Zwitserlood, 1994; Jarema et al., 1999; Kehayia et al., 1999; Libben et al., 2003) have shown that priming with either constituent of a compound (e.g. *tea* or *cup* for *teacup*) facilitates lexical decision performance, indicating that both constituents contribute to compound access. This bidirectional constituent priming effect has been confirmed across multiple languages, including Basque (Duñabeitia et al., 2009) and Greek (Manouilidou et al., 2012), further supporting models of parallel constituent activation.

Additionally, masked priming studies, which capture the earliest stages of lexical processing (Forster & Davis, 1984), have provided converging evidence. Shoolman and Andrews (2003) and Fiorentino and Fund-Reznicek (2009) observed equivalent facilitation effects from both the first and second constituent primes, suggesting a position-independent, automatic activation process. Similar findings have been reported in Greek by Manouilidou et al. (2012), reinforcing the idea of early and equal constituent activation during compound recognition. However, not all findings support the symmetrical role of constituents. Pollatsek et al. (2000), using eye-tracking in Finnish, demonstrated that the frequencies of the whole compound and that of the second constituent (but not the first) significantly influenced gaze durations. Similarly, Juhasz et al. (2003) reported robust frequency effects for second constituents across multiple tasks, including lexical decision and eye-tracking in English, indicating a possibly dominant role for the second morpheme in some processing contexts.

These findings align with dual-route models of lexical access, which posit that compound words can be accessed both holistically (which explains whole word frequency effects) and via morphological decomposition (which explains frequency effects of constituents). In other words, high-frequency compounds are likely retrieved as whole units, while low-frequency compounds with high-frequency constituents tend to undergo decomposition. This view is summarized within the framework of the *Maximization of Opportunity* model (Libben, 2006), according to which compound processing involves the activation of both constituent and whole-word representations. In cases where semantic conflict arises (e.g. *butterfly ≠ butter + fly*), corrective post-activation mechanisms are engaged to suppress misleading interpretations (Libben, 2006).

Within this prevailing dual-route perspective, a key question remains: which variables are encoded in a compound's mental representation and influence access? As summarized by Libben et al. (2020), a wide range of studies have identified several factors that modulate compound processing. These include word length and frequency (Andrews, 1986; Bertram & Hyönä, 2003; Juhasz et al., 2003; Andrews et al., 2004), semantic transparency (Sandra, 1990; Marslen-Wilson et al., 1994; Zwitserlood, 1994; Libben et al., 2003; Gagné et al., 2020), relational structure (Gagné, 2002; Gagné & Spalding, 2009), and headedness (Jarema et al., 1999; Marelli et al., 2009; Manouilidou et al., 2012[30]; Arcara et al., 2014; Gagné et al.,

30 This study is the only one among the ones cited that focused on the processing of *coordinative compounds*. A coordinative compound (also called a dvandva compound, especially in linguistic typology) is a compound word in which both constituents are of equal status and contribute equally to the overall meaning. Rather than one word modifying the other (as in *toothbrush*), in coordinative compounds, both parts refer to separate entities that are jointly denoted, e.g. *bittersweet*. In coordinative compounds in Greek, it is not clear whether the second constituent of coordinative compounds assumes the role of the head, because the two coordinated constituents are of the

2020). In the following sections, these factors will be explored in more detail through the lens of psycholinguistic evidence.

3.3.1 Length and frequency effects

Length and *frequency* are well-established factors influencing compound word processing. In an eye-tracking study, Bertram & Hyönä (2003) manipulated the frequency of the first constituent in both short and long Finnish compounds. Their findings revealed that in longer compounds, first-fixation durations were significantly affected by constituent frequency, suggesting that increased compound length promotes morphological parsing, i.e., longer compounds are more likely to be decomposed into their constituents during processing (see also Bertram et al., 2011). However, this effect did not replicate in English (Juhasz, 2008), indicating that it may be language-specific.

Further evidence from eye-tracking comes from Kuperman et al. (2008, 2009), who demonstrated that the frequency of the whole compound modulates the influence of the first constituent's frequency: the higher the compound frequency, the smaller the effect of the constituent frequency. These findings, observed in both Finnish and Dutch, point to an early-stage interaction between whole-word and constituent-level properties, emerging as early as the first fixation on the compound (see also Hyönä & Pollatsek, 1998; Juhasz et al., 2003; Andrews et al., 2004; Duñabeitia et al., 2007; Gagné et al., 2009; Bertram et al., 2011; Marelli & Luzzatti, 2012; Arcara et al., 2014; Janssen et al., 2014; Juhasz, 2018, for broader evidence on frequency effects in compound recognition).

3.3.2 Semantic transparency effects

Semantic transparency refers to the degree of alignment between the meanings of a compound's constituents and the overall meaning of the compound itself (e.g. *buttermilk* vs *butterfly*). There is consensus in the psycholinguistic literature that semantic transparency facilitates compound processing (Libben et al., 2020). Sandra (1990) was among the

same grammatical category and the meaning of the compound as a whole cannot be interpreted as "type of X" as is the case with subordinative compounds.

first to emphasize this effect, investigating the role of transparency in Dutch compounds through a semantic priming LDT. The study revealed that RTs were significantly shorter when compounds were preceded by semantically related primes, but only for semantically transparent targets (e.g. *death* primed *birthday*, whereas *moon* did not prime *Sunday*). Similar facilitative effects were observed under masked priming conditions (Hwaszcz et al., 2017).

Consistent findings have been reported in other languages. For instance, Isel et al. (2003) demonstrated that in German compounds, priming effects for the modifier constituent occurred only when the head constituent was semantically transparent. These results align with additional evidence from sentence-reading paradigms (Juhasz, 2007) and neuroimaging studies using tasks such as plausibility judgments and accessibility assessments (see Chapter 4, § 4.1.3.). They all suggest that constituent access is modulated by the semantic properties of the compound as a whole. At the same time, these findings contrast with a substantial body of research on constituent priming, which supports automatic access to constituents regardless of transparency (Zwitserlood, 1994; Jarema et al., 1999; Libben et al., 2003; Smolka & Libben, 2017). Supporting this position, masked priming studies have also reported constituent activation in both transparent and opaque compounds (Shoolman & Andrews, 2003; Fiorentino & Fund-Reznicek, 2009), indicating that semantic transparency may not uniformly constrain access to constituents. The Meaning Computation Approach proposed by Ji et al. (2011), also supports the notion that constituent activation occurs independently of a compound's transparency. In a series of six lexical decision experiments, the authors demonstrated that the morphological structure of compounds triggers decomposition irrespective of transparency. Their findings suggest that both lexical and semantic representations of the constituents become available during processing. Crucially, they observed that an attempt at meaning integration is always initiated, but its outcome depends on the transparency of the compound: while integration facilitates processing for transparent compounds, it may interfere with recognition of opaque ones, where the composed meaning diverges from the holistic meaning of the compound (see also Inhoff et al., 2000; Frisson et al., 2008; Libben, 2010).

Nonetheless, it has been proposed that the discrepancies observed in the literature may stem from differences in experimental methodology, as constituent priming and semantic priming tasks likely tap into distinct levels of linguistic processing (Libben et al., 2003). Specifically, Libben's (1998) Conjunctive Activation Approach posits that semantic transparency effects arise from interactions at both *lexical* and *conceptual* (semantic) levels. According to this model, both the compound and its constituents have distinct representations at each level of processing. At the *lexical* level, the representation of a compound is consistently associated with its constituent morphemes, regardless of semantic interpretation. This structural linkage explains the consistent facilitation effects found in constituent-priming paradigms, even for semantically opaque compounds (e.g. Zwitserlood, 1994; Libben et al., 2003; Smolka & Libben, 2017). In contrast, at the *conceptual* or semantic level, the connection between the compound and its constituents depends on semantic transparency. Transparent compounds maintain semantic ties to their constituents, allowing for facilitation effects from semantically related primes, as demonstrated in the studies by Sandra (1990) and Hwaszcz et al. (2017). Opaque compounds, lacking such semantic connections, fail to show similar priming effects in tasks that engage conceptual processing. These findings underscore that the influence of semantic transparency on compound processing is task-dependent, with different experimental paradigms engaging distinct levels of lexical and semantic representation (Libben, 1998; Libben et al., 2003).

What to keep in mind from the above is that when the semantic relationship between a compound's constituents is transparent (e.g. *teacup*), a processing advantage is typically observed. However, constituent priming studies often reveal activation regardless of transparency, suggesting different processing mechanisms. Libben's (1998) dual-level model explains this by distinguishing between lexical (structure-based) and conceptual (meaning-based) access. Finally, compositional and meaning-computation approaches argue that semantic integration is always attempted but succeeds only for transparent compounds.

3.3.3 Relational structure effects

Relational structure refers to the conceptual or semantic relationship that holds between the constituents of a compound word, predominantly a nominal compound. For example, a *wildcat* is a TYPE OF *cat*, while a *snowman* is a *man* MADE OF *snow*. What makes nominal compounds particularly intriguing is that the relation between the two nouns is not overtly expressed at any linguistic level; instead, it is implied by the compound structure itself. Over the years, accumulating evidence has supported the role of relational structures in compound word processing (for a review: Gagné & Spalding, 2014).

An early investigation by Coolen et al. (1991) on the processing of novel compounds by using a LDT found that the more interpretable a compound was, based on the meaning of its constituents, the more difficult it was for the participants to reject it. In a follow-up study, the participants paraphrased these compounds, and their paraphrases were categorized using Levi's (1978) set of semantic relations (e.g. *plastic bag* = MADE OF; *blueberry muffin* = HAVE). The results indicated that highly interpretable (i.e., transparent) compounds were more frequently paraphrased using one of Levi's semantic relations compared to less interpretable (i.e., opaque) ones. This led Coolen et al. (1991) to propose that part of the lexical decision process may involve integrating meaning through relational structures.

Subsequent studies have supported this view. Gagné (2000, 2001, 2002) found that the ease of interpreting novel compounds is influenced by the availability of particular semantic relations associated with the modifier. For instance, Gagné and Shoben (1997) demonstrated that compounds in which the modifier typically appears with a common relation (e.g. *mountain* in *mountain cloud*, indicating a LOCATED relation) were processed faster than compounds using less typical relations (e.g. *mountain magazine*, indicating an ABOUT relation; see also Spalding et al., 2010).

Relational structure has also been shown to affect the processing of existing compounds. In a LDT with priming, Gagné et al. (2009) found that RTs were faster when a compound (e.g. *snowman*) was preceded by a prime sharing the same semantic relation (e.g. *snowball*, both expressing a MADE OF relation) than when it was preceded by a compound with a different relation (e.g. *snowshovel*, expressing a FOR relation). Moreover, relational priming was modulated by both the semantic relation and the constituent's syntactic role. Specifically, priming effects occurred only when the constituent repeated across prime and target appeared in the same morphosyntactic position. For example, *fur gloves* was processed more quickly when preceded by *fur blanket* than by *fur trader*, but no facilitation was observed when preceded by compounds like *acrylic fur* or *brown fur*. These findings suggest that relational information is processed in tandem with the constituent's grammatical role (see also Spalding & Gagné, 2011; Gagné & Spalding, 2013; Schmidtke et al., 2018).

3.3.4 Headedness and position effects

The *head* constituent plays a crucial role in compound structures, as it determines the percolation of morphosyntactic features (e.g. grammatical category, inflectional class) and conveys the core meaning of the entire compound. This linguistic prominence has prompted several studies to explore whether the head's theoretical status is mirrored in real-time compound processing. Indeed, activation of the head constituent has been observed to depend on semantic transparency: compounds with transparent heads elicit faster responses than those with opaque heads in LDTs using priming paradigms (Sandra, 1990; Isel et al., 2003; Libben, 2010; Libben & Weber, 2014).

However, the nature of the headedness effect remains unresolved, partly due to the confounding role of the constituent position. In English and other languages, the head typically appears in the second position, a pattern known as the "Right-hand Head Rule" (Williams, 1981), making it difficult to distinguish the cognitive impact of headedness from a general positional advantage. For example, facilitation for the first (non-head) constituent has been reported in English (Libben, 1998), Polish, and Greek (Kehayia et al., 1999), while other studies have found an advantage for the second position using constituent priming paradigms. Duñabeitia et al. (2007), comparing Basque (head-initial compounds) and Spanish (head-final compounds), found that second-constituent frequency similarly influenced RTs in both languages, pointing towards a general second-position effect rather than a headedness-specific one.

To disentangle the effects of headedness and constituent position, researchers have turned to languages like Italian and French, which include both head-initial and head-final compounds (see Jarema et al., 1999; Marelli et al., 2009; Marelli & Luzzatti, 2012; Arcara et al., 2014). These studies, by using a variety of methodologies ranging from simple LDTs to eye-tracking, indicate that the head-modifier structure is not merely a linguistic abstraction but is cognitively represented. Notably, some studies report a processing advantage for head-initial compounds (Arcara et al., 2014), while others show a facilitation for head-final ones (Marelli et al., 2009; Marelli & Luzzatti, 2012). Nonetheless, the evidence remains inconclusive regarding whether head-initial or head-final compounds are generally processed more efficiently.

Finally, research on exocentric compounds, those lacking an internal head (e.g. *red-haired*), is limited. Marelli et al. (2009) investigated verbal-noun exocentric compounds in Italian using a constituent priming paradigm. Their findings revealed equal priming for both constituents, suggesting the absence of a positional effect and supporting a flat internal structure.

3.3.5 Interim summary

Compounds can be processed either holistically or through decomposition, making them ideal for studying lexical access and morphological representation. Early LDTs showed that the participants more quickly rejected non-compounds when the first constituent was a nonword, supporting the idea of pre-lexical decomposition. Subsequent studies found that both the first and second constituents independently facilitate recognition, with constituent priming effects being bidirectional and consistent across languages. Masked priming studies reveal early and automatic activation of both constituents, although eye-tracking studies sometimes show a dominant role for the second constituent. On the other hand, the Maximization of Opportunity model (Libben, 2006) suggests that both whole-word and constituent representations are simultaneously activated, given that processing is also influenced by word length and frequency, with longer compounds more likely to be decomposed, while high whole-word frequency can override constituent frequency effects.

Interesting insights come from studies that addressed the role of *semantic transparency* (e.g. *teacup* vs *butterfly*). Semantic transparency typically facilitates processing, although priming studies show constituent activation even for opaque compounds, in line with a decompositional route to lexical access. *Relational structure* (e.g. *snowman* = MADE OF snow) also shapes compound processing, with common relations such as LOCATED or HAVE leading to faster recognition. Priming studies further show that matching in semantic relation and syntactic role enhances recognition. Finally, *headedness* plays an important role, although its effect is difficult to isolate from constituent position. Cross-linguistic findings are mixed, with no clear consensus on whether head-initial or head-final compounds are processed more efficiently.

The following chapter will provide more insights into complex word processing and some of the issues raised in this chapter through neuroimaging studies.

4 Morphology in the brain: the view from neuroimaging

The present chapter aims to provide a snapshot of how cognitive neuroscientists have attempted to address the general questions regarding morphological processing outlined in Chapter 3. The neuroimaging approach pays special attention to two sources of information that can shed light on the ongoing debates: 1) the time course of the morphological decomposition processes of complex words (inflected, derived, and compound), and 2) the brain networks and areas responsible for the processing of polymorphemic words.

The chapter covers a wide range of electro- and magnetoencephalography (EEG and MEG, respectively) as well as functional magnetic resonance imaging (fMRI) studies that focus on morphological processing. I will present the findings with respect to the temporal and spatial dynamics of morphologically complex word processing, and I will attempt to interpret them with respect to current psycholinguistic models.

4.1 Electrophysiology of language

Electroencephalography (EEG) is a neuroimaging technique widely used in linguistics for its fine-grained temporal tracking of brain activity. With an extremely high temporal resolution in the millisecond range, EEG captures electric potential differences, typically between (a) the 30–100 'active' electrodes placed across the scalp and (b) a relatively inactive reference electrode, thereby recording brain activity. A conductive gel is applied between the electrodes and the skin to establish a stable electrical connection. Each scalp electrode records electrical potentials (voltage) changes originating from a specific subset of brain structures, generating distinct waveforms at different electrode sites. However, in addition to brain activity, these waveforms may also include electrical potentials from muscle movement, eye movement, and external electrical sources (Luck, 2014).

Event-Related Potentials (ERPs)

Event-Related Potentials (ERPs) are neural responses associated with specific events, whether sensory, cognitive, or motor, extracted from EEG recordings through an averaging method. The resulting ERP waveforms consist of a sequence of positive and negative voltage deflections, referred to as peaks, waves, or components.[31] The voltage at each time point in the waveform reflects a certain pattern of brain activity (Luck, 2014). An ERP component represents a scalp-recorded neural signal generated by a specific set of neuroanatomical units when humans perform specific tasks, or rather, when a neural unit or circuit performs a certain operation. That is why certain ERP components are often discussed as reflections of specific cognitive processes.

ERP components are typically named based on their polarity (negative or positive), latency (in milliseconds), and topographical distribution (Luck, 2014). For instance, a negative-going component is labelled with an *N*, a positive-going one with a *P*. The number following these labels denotes the component's peak latency, for example, the N400 component peaks at 400 milliseconds post-stimulus onset (PSO). ERP components play a crucial role in differentiating the processing of semantics, morphology, and orthography (Royle et al., 2010). Those specifically related to language processing are briefly reviewed below, and they are presented in temporal order. A summary of their features can be found in Table 1. It is important to note that I will discuss ERP components only within the relevant linguistic context, that is, morphological processing, and only those components that appear in the studies I will present. For the sake of focus and conciseness, other characteristics of ERP components will be neglected.

Early ERP components (MMN, N250, P300)

Several ERP components sensitive to morphological processing have been identified between 100 and 300 ms, with overlapping temporal profiles and functional associations. These include: the MMN, the N250, and the P300. While it might appear as if the differences are straightforward, one should keep in mind that the distinctions between all these components and what they are responding to can be murky.

31 These terms do not necessarily refer to the same pattern or feature, but explaining their differences is beyond the scope of this chapter.

Mismatch Negativity (MMN)

The Mismatch Negativity (MMN) is an ERP component highly sensitive to acoustic variation, and is commonly interpreted as an index of change detection at the neurophysiological level. It provides insights into both the storage and combinatory mechanisms of language processing. The MMN typically emerges within 100–200 ms following an acoustic deviance, such as hearing [pa] within a repeated series of [ba]. The MMN is relevant in the context of the present monograph and morphological processing, as it seems to be modulated by the morphological structure and lexical status of standards and deviants (words vs non-words and nouns vs verbs). Research has shown that monomorphemic real words elicit larger MMN responses compared to pseudowords (Pulvermüller et al., 2001; Shtyrov & Pulvermüller, 2002; Garagnani et al., 2009; Shtyrov et al., 2011). This has been attributed to the automatic activation of stored lexical representations in long-term memory, in contrast to the reduced or absent activation for non-existent pseudowords (Shtyrov et al., 2010). Additionally, the MMN is sensitive to morpho-syntactic structure. Grammatically well-formed words and phrases elicit smaller MMN responses than ungrammatical combinations (Pulvermüller & Shtyrov, 2003). For example, syntactically incorrect combinations, such as **we talks* elicit stronger MMN responses compared to correct ones like *he talks* (Pulvermüller & Shtyrov, 2003; Shtyrov et al., 2003). This subtype of MMN, referred to as the syntactic MMN (sMMN), reflects the brain's early, automatic response to violations of syntactic regularity (Pulvermüller & Shtyrov, 2003; Shtyrov et al., 2003; Bakker et al., 2013). Related to our topic is the lexical MMN (lMMN), which has been observed in response to spoken words that evoke greater MMN amplitudes than acoustically similar pseudoword syllables. This effect has been consistently reported across studies (Korpilahti et al., 2001; Pulvermüller et al., 2001, 2004; Shtyrov & Pulvermüller, 2002; Endrass et al., 2004; Pettigrew et al., 2004; Shtyrov et al., 2005, 2010).

N250

This represents another negative event in the early time window, with an onset around 175 ms, a duration of approximately 150 ms, and a peak at around 250 ms. It has a broad scalp distribution, with the largest effects over the more frontal sites. It is used as an index of lexical form and grammatical features linked to word structure or morphosyntactic processing (Royle

& Steinhauer, 2023). It is occasionally labelled as the early N400 (Royle & Steinhauer, 2023). The N250 has been associated with morph-orthographic processing in various papers by the Holcomb lab (e.g. Holcomb & Grainger, 2006, Holcomb & Grainger, 2007). They suggest that the N250 may reflect the processing of sub-letter visual feature representations and sub-word orthographic representations (i.e., letters and letter clusters). In particular, they propose that the amplitude of the N250 may reflect the degree of mismatch between letter and letter-cluster representations that are activated by the prime stimulus, and those representations receiving activation from the target.

P300

The P300 family of ERP components is observed across a wide range of tasks. The classic P300 (or P3b) is a positive-going waveform that typically exhibits a centro-parietal scalp distribution, peaking around 300 ms after stimulus onset. Some researchers differentiate between an early and a late P300 (which also includes the P600, according to some), with the latter peaking between 600 and 800 ms post-stimulus (Hill et al., 2005). Several factors influence P300 amplitude, including stimulus novelty and probability, task relevance, attentional demands, and stimulus saliency (see Bashore & Van der Molen, 1991; Kok, 2001, for reviews). Additionally, the P300 amplitude is often interpreted as reflecting the updating of working memory in response to unexpected stimuli – an idea central to the context updating theory (Donchin & Coles, 1988). Alternatively, it has been proposed to signal the closure of a perceptual episode once expectations are met, as suggested by the context closure theory (Verleger, 1988).

Later ERP components (N400/LAN/P600)

The later components include responses peaking between 300–700 ms, which have their origins in various scalp locations, and they signal diverse language functions, related to morphological processing. As with the earlier components, the distinction between some of the later components is also a challenging task.

N400

One of the most extensively studied neural responses related to language processing is the N400 component, first identified by Kutas and Hillyard (1980). The N400 is a negative-going ERP that typically emerges between

300–500ms PSO, peaking around 400 ms, and it is most prominent over central and parietal electrode sites. It was initially observed in response to semantic anomalies, such as in the sentence *He spread the warm bread with socks* (Kutas & Hillyard, 1980). However, subsequent research has demonstrated that the N400 is also elicited by isolated words, pronounceable pseudowords, and even pictures (Lau et al., 2008; Kutas & Federmeier, 2011), as well as by syntactic violations (Luck, 2014).

Generally, the N400 is understood to reflect processes involved in lexical access and the retrieval of semantic information from memory (Kutas & Federmeier, 2000, 2011; Lau et al., 2008, 2009). It is also sensitive to semantic integration based on preceding context (Kutas et al., 2006; Hagoort & van Berkum, 2007; Leinonen et al., 2008). Moreover, the N400 has been shown to index the semantic integration of morphemes in incorrectly derived lexical items, suggesting that it is sensitive to failures in lexical access and that morphological decomposition is a necessary step in computing word meaning from syntactic and semantic properties (Janssen et al., 2006; Leinonen et al., 2008; Leminen et al., 2010; Havas et al., 2012; Schuster & Lahiri, 2019). Thus, the amplitude of the N400 is commonly interpreted as reflecting the degree of difficulty in accessing and integrating lexico-semantic information.

The N400 is modulated by lexical factors such as lexicality and word frequency. Words that do not exist in the lexicon (e.g. pronounceable pseudowords) elicit larger N400 amplitudes compared to real words (Kutas & Hillyard, 1980, 1984; Osterhout et al., 1997), while unpronounceable pseudowords do not elicit N400 (Holcomb, 1993). Similarly, low-frequency words produce larger N400 responses than high-frequency ones (Bentin et al., 1985; Holcomb & Neville, 1990; Chwilla et al., 1995).

Although N400 amplitudes are slightly larger at right-hemisphere electrode sites, neuroimaging and source localization studies suggest that the neural generator of the N400 is located in the left temporal lobe (Luck, 2014). This apparent discrepancy is thought to arise from the orientation of the dipole in the left hemisphere, which points medially rather than directly upward, thereby affecting the scalp distribution of the signal (Luck, 2014).

Left Anterior Negativity (LAN)

The Left Anterior Negativity (LAN) is another negative-going ERP component, typically arising around 300–500 ms PSO. LANs are more reliable in auditory than reading studies, and they are elicited in response to morphosyntactic violations, specifically in cases of overregularization (**breaked* vs *broke*) and inflection or agreement errors such as subject-verb agreement errors. The LAN is considered a marker of morpho-syntactic rule processing or rule-based processes (Friederici, 2002; Friederici & Kotz, 2003; Friederici & Weissenborn, 2007; Rossi et al., 2005), while N400s have been linked to lexical-semantic retrieval. Additionally, the LAN has been interpreted as reflecting working memory demands during sentence processing (Fiebach et al., 2002; Kluender & Kutas, 1993).

Something to note is that the N400 and LAN are not trivial to distinguish in the sense that they have the same temporal profile and the same polarity.[32] They could be distinguished based on topography, but in the literature one can find many cases identified by researchers as an N400 that resemble a LAN (and vice versa, but to a lesser extent). In such cases, we are left with only the specific, experimental task and thus functional interpretation of the component, providing a clear distinction, which is, of course, far from ideal when we are interested in interpreting language-related domains.

P600

The P600 is a positive-going ERP component that typically emerges between 500–700ms PSO, peaking around 600 ms, and it is associated with bilateral activation in the posterior superior temporal cortices (Grodzinsky & Friederici, 2006; Service et al., 2007). It has traditionally been identified as a neural response to syntactic violations and syntactically complex structures (Osterhout & Holcomb, 1992; 1995; Coulson et al., 1998; Friederici, 2002; Friederici & Kotz, 2003; Friederici & Weissenborn, 2007; Münte et al., 1997). However, the P600 has also been linked to semantic anomalies, particularly those involving violations of animacy or argument structure – for example, in sentences like *Every morning at breakfast the eggs would eat…* (Kuperberg, 2007). This broader sensitivity has led to interpretations of the P600 as reflecting not only syntactic reanalysis but also post-hoc integration or repair processes at the sentence level (Friederici & Weissenborn, 2007; Kuperberg, 2007) or individual words (Palmović & Maričić, 2008).

32 But note Guajardo and Wicha (2014), one of the few studies that tries to distinguish LAN and N400 in the same experiment in response to morphosyntactic and morphosemantic manipulations of gender-marked post/nominal adjectives.

More generally, the P600 is thought to reflect syntactic reanalysis processes, especially in response to words that are ungrammatical in the context of the preceding sentence (Friederici et al., 1993; Münte et al., 1993, 1997; Osterhout et al., 1994; Friederici, 1995; Coulson et al., 1998). This component often co-occurs with the LAN, with the LAN reflecting the early detection of syntactic anomalies and the P600 indexing subsequent syntactic repair or reanalysis (Palmović & Maričić, 2008). According to Gunter and Friederici (1999), the P600 reflects a controlled, language-related process that may be initiated relatively automatically in response to salient syntactic violations, such as those that disrupt thematic role assignment.

Table 1: List of ERP components used in language research related to morphological processing

Component	**Time window (in ms)**	**Functional significance**	**Origin**
MMN	100–200	detection at the neurophysiological level lexicality, syntactic structure	superior temporal cortex, frontal cortex
N250	150–250	morpho-orthographic processing	broad scalp distribution with the largest effects over the more frontal sites
P300	150–300	response to novelty and probability	centro-parietal scalp distribution
LAN	300–500	morphosyntactic violations, syntactic rule processing	left frontal or fronto-temporal cortex
N400	300–500	semantically incongruent information, sensitivity to meaning	superior temporal cortex
P600	500–700	sensitivity to syntactic information	temporal cortex bilaterally

4.1.1 EEG studies on inflectional morphology[33]

Inflectional morphology has been the focus of many EEG studies, targeting either *morphophonological* (word level) or *morphosyntactic* (sentence level) processing. The distinction between the two is not always clear. However, we can roughly say that the former refers to questions restricted to the word level, such as the use of *regular* vs *irregular* morphology (see also Chapter 3, § 3.1.2), and the latter refers mostly to agreement morphology errors or violations, or to the processing of gender marking in a sentential context. While both types of studies offer valuable insights into the processing of inflectional morphology and language processing in general, given the orientation of the chapter and the monograph, I will focus on *morphophonological* (word level) processing of inflectional morphology.

The investigation of inflectional morphology at the word level is one of the most studied forms of word morphology in EEG research. This is partly because it initially offered a clear way to test how the brain processes language, particularly in distinguishing between words formed by the application of rules (*walk* → *walked*) and those expected to be directly recalled from memory such as irregular verbs (*taught*), a question known as the *past-tense debate* (see § 3.1.2). EEG studies use the brain's electrical activity to study this distinction and have expanded beyond English to other languages such as Italian, Spanish, and Finnish.

The main methodological tool in the investigation of inflectional morphology at the word level is the *priming paradigm,* as is the case with behavioral experiments (§ 3.1.2). During this, the participants are shown the infinitival form of a verb (e.g. *walk*) as a prime, immediately followed by the target word, which can either be morphologically related (e.g. the verb's past-tense form, *walked*) or a different unrelated word (e.g. *teach*). Researchers measure how the brain responds to the target after a related or unrelated prime. In these paradigms, the time course of complex word processing is assumed to be observed either in N250 or in N400 effects, corresponding to earlier stages of processing, either in terms of mapping orthographic representations to lexical-orthographic (N250) or the mapping of morpho-lexical

33 The reader is also referred to Royle and Steinhauer (2023) and to Leminen et al. (2019), which offer reviews of neuroimaging studies dedicated to inflection, derivation and compounding.

form to meaning (N400) (Holcomb & Grainger, 2006). The priming studies I will review follow the above pattern.

An early study on verbal inflection (Weyerts et al., 1996) using long-lag priming (~13 intervening items between prime and target) found that regular verb pairs in German (e.g. *tanzen* → *getanzt* 'to dance–danced') produced significant N400 reductions, comparable to identity priming (*getanzt* → *getanzt*), suggesting processing beyond the form level. In contrast, irregular pairs (e.g. *schreiben* → *geschrieben* 'to write–written') did not show significant effects. Similarly, Münte et al. (1999) investigated long-lag morphological priming in English using regular (e.g. *walked* → *walk*) and irregular (e.g. *went* → *go*) verb pairs, including both real and novel forms (e.g. **broded* → **brode*). They found reduced N400 amplitudes for regular verbs compared to irregular ones. This pattern was replicated by Rodriguez-Fornells et al. (2002) for Spanish. In all these studies, priming effects were not attributable to orthographic overlap, challenging the form-based accounts.

A different group of studies directly compared the effects of morphological priming to orthographic/phonological (i.e., formal) and semantic priming. Domínguez et al. (2004) conducted ERP experiments on lexical access using Spanish inflected morphological pairs (*hijo* → *hija* 'son–daughter'). They found robust morphological priming effects distinct from semantic or formal (orthographic) priming. Comparisons included unrelated pairs, stem homographs (*foco* → *foca* 'floodlight-seal'), orthographic neighbors (*rasa* → *rana* 'flat-frog'), and synonyms (*cirio* → *vela* 'candle$_{\text{Fem}}$ candle-$_{\text{Masc}}$). Morphological pairs showed sustained N400 attenuation (250–650 ms), unlike other conditions. Homographs showed early N400 reduction (N250) followed by a delayed increase; orthographic neighbors showed no priming, and synonyms only showed late effects (450–650 ms). The authors proposed three stages of processing: (1) stem-affix segmentation and form-level priming (250–350 ms), (2) lemma-level activation (350–450 ms), and (3) semantic integration (450–650 ms). Only morphological pairs showed reduced N400 across all stages, suggesting that models without morphological representation cannot fully account for these effects.

Finally, Leminen and Clahsen (2014) examined inflected adjectives of German in two cross-modal ERP priming experiments (see § 3.1.2). In the first, they tested lexical-semantic priming effects comparing morphologically related adjective forms (*neutrals* → *neutral* 'neutral-neutral') to an identical repetition priming (*neutral* → *neutral*) and an unrelated control condition (*verbal* → *neutral* 'verbal-neutral'). They found that prime–target pairs that share the same lemma were associated with a reduced centro-parietal negativity relative to the unrelated control condition. This was the case for the related as well as the identity condition compared to the unrelated control condition. In addition, the identity condition also elicited a reduced negativity (already seen in the 200 to 300 ms but more pronounced in the later 300–400 ms time window) at centro-parietal sites compared to the related condition. In the second experiment, they tested priming with two inflected adjectival forms (in *-s* and *-m,* e.g. *sattes* → *satte*, *sattem* → *satte*), each of which differed with respect to the number of morphosyntactic features it encodes. That is, while *-m* encodes dative, *-s* encodes both nominative and accusative. The most important finding from experiment 2 was that relative to *-m*, the *-s* prime condition yielded a reduced centrally distributed positivity between 200 and 300 ms, signalling differences in morphosyntactic feature overlap between *-s* and *-m* primes and their targets. They interpreted these results as indicating that grammatical information becomes available earlier than semantic information, providing support for structure-first models of language processing.

Important insights come from masked priming experiments, which focus on form and morphological effects independently of semantics (see § 3.1.2). Royle et al. (2012) used French stimuli to directly compare morphological (e.g. *cassait* → *casse* 'broke → break'), semantic (e.g. *brise* → *casse* 'break → break'), and orthographic (e.g. *cassis* → *casse* 'blackcurrant → break') priming using short 50 ms intervals. Semantic primes showed no ERP effect, orthographic primes produced weak N250 modulations, while morphological primes triggered strong and sustained N250–N400 reductions. These results highlight the privileged status of morphological priming, beyond orthographic effects and excluding semantic influence. Morris and Stockall (2012) also report an N250 followed by an N400 in a masked priming task using stimuli from English. Based on this, the authors argue for a rapid, form-based decomposition of all morphologically complex words, associating early word recognition processes with both regular and irregular allomorphy.

Another study on English by Rastle et al. (2015), also using masked priming, reports that morphological priming with regular inflections led to a very small reduction of the N250 amplitude and a substantial attenuation of the subsequent N400 component. In contrast, priming with irregular inflections displayed a later and smaller N400 amplitude reduction. Taking these two findings together, the authors suggest that the two types of inflections trigger different brain responses. Specifically, the stems of regular prime-target pairs (*walk* → *walked*) overlap at both the early morpho-orthographic/morphophonological level and the later lexical semantic level of representation, while stems of irregular inflections (*teach* → *taught*) overlap only at the later lexical semantic level of representation.

Apart from the above priming or masked priming studies, two studies on Finnish used simple LDTs visually (Lehtonen et al., 2007) and both auditorily and visually (Leinonen et al., 2009). Both studies report increased N400 amplitudes for inflected words as opposed to monomorphemic words, pointing towards a morphological processing cost of combining stems and suffixes in order to provide meaning to the morpheme combination. Specifically, Lehtonen et al. (2007) aimed to reveal whether the processing cost stems from decomposition at the early visual word form level or from re-composition at the later semantic–syntactic level. They used words with real suffixes and pseudostems (e.g. *värö+ssä*), real stems and pseudosuffixes (e.g. *onni+tla*), monomorphemic pseudowords (e.g. *kamsteri*), and illegal combinations of real stems and suffixes (e.g. *lammasen* instead of the correct *lampaan*). They found that real suffixed and monomorphemic words elicited smaller N400s than various types of pseudowords. The effect was modulated by word frequency: high-frequency multimorphemic words were processed more easily than monomorphemic ones, but this advantage disappeared at lower frequencies. This was interpreted by the authors as suggesting that the processing cost stems mainly from the semantic-syntactic level.

Finally, Leinonen et al. (2009) used Finnish inflected vs monomorphemic words and pseudowords during a lexical decision task to investigate how the input modality (visually and auditorily) affects the processing of a morphologically complex word. At the behavioral level, the inflected words elicited a processing cost with longer decision latencies and higher error rates. At the neural level, pseudowords elicited an N400 effect, which was more pronounced in the visual modality. Inflected real words elicited an N400 effect in both modalities, which, however, differed in topography and latency. The authors claim that the N400 effect for inflected words most probably reflects access and possible integration of the stem and suffix. They interpret the results as suggesting that the inflectional processing cost stems from the later, lexical-semantic stage of processing in both modalities. The ERP responses to inflected pseudowords did not differ from the ERP responses to monomorphemic pseudowords in either modality, suggesting that combinatorial case-inflection processing requires a real word stem to proceed.

To understand the above results and their significance for the literature on the processing of inflectional morphology, we should consider the mechanisms behind the simple LDT which measures increased processing load due to morphological complexity and the LDT with priming which tries to facilitate processing due to preactivation of information (here: morpho-phonological units and the conceptual-semantic meaning associated with them). The studies reviewed here showed that in the simple LDTs (Lehtonen et al., 2007; Leinonen et al., 2009) morphological processing is demonstrated by an increase of the N400 amplitude, whereas in the priming studies it is reflected by a decrease of the target word's N400 (and N250) amplitude, due to preactivation of stem morphemes by the prime. At first sight, these two effects appear to go in opposite directions (increase vs decrease of N400 amplitudes). However, they can both be explained only if one assumes that *morphological decomposition* takes place during real-time word processing. If words are not decomposed but processed as one (stored) unit, one would not expect either differences between regulars and irregulars in priming, or stronger effects of morphological compared to semantic + orthographic priming, *and* one would not expect N400 processing differences between monomorphemic and polymorphemic words that are otherwise well matched.

What remains to be seen is whether these effects, which advocate for morphological decomposition for inflected words, will also hold for derived words as well or whether other factors, such as the ones outlined in Chapter 3 (§ 3.2), will play a decisive role in triggering brain responses.

4.1.2 EEG studies on derivational morphology

The purpose of this section is to review EEG studies that have tackled derivational morphology to contribute to the general question of how, when, and where in the brain derived words are decomposed and their morphological constituents processed. The main question of interest is whether individual morphemes that constitute a polymorphemic affixed word (e.g. the stem *play* and the suffix *-er* in the suffixed word *player*) are accessed before reaching the meaning of the whole string (namely, the meaning of *player*), and if that were the case, the precise stage of the word recognition stream at which access to the stems and affixes may take place.

As with behavioral studies, the reason for exploring derivational morphology as a separate domain within the general question of morphological processing lies in the inherent differences between the two operations (inflection vs derivation), as outlined in § 1.3. Derivational morphology is more "lexical", and inflectional morphology is more "grammatical". Derivational morphemes carry lexical meaning, and they can potentially change the syntactic category of the base root. These two properties should lead to phenomena (including in terms of ERP effects) that are simply non-applicable to inflectional morphology. As such, they merit their own investigation.

As with the investigation of inflection, most EEG studies on derivational morphology use stimuli from Indo-European languages, such as English, German, French, and Spanish, as well as Finnish from the Uralic language family (see Leminen et al., 2019). The most common paradigm is the *violation of derivational rules paradigm*, in which pseudowords violating derivational rules are presented either in a sentential context or as single words. *Priming tasks* have also been used with either masked or overt prime, with visual or auditory prime presentations.

Starting with the *violation paradigm*, the four studies that used violations of derivation rules in terms of an inappropriate stem + suffix combination that were presented as sentential content (Leinonen et al., 2008; Janssen et al., 2006; Bölte et al., 2009; Havas et al., 2012) report that suffixed derived pseudowords evoke either a LAN (Bölte et al., 2009) or an N400 pattern (Leinonen et al., 2008; Janssen et al., 2006), thus suggesting that the recognition of derived word forms engages both word-level (lexical-semantic) and decompositional (morpheme-based) processes. Interestingly, Havas et al. (2012) contrasted violations of derivational morphology, e.g. *blanco* 'white' → **blancura* 'whiteness' instead of the correct form *blanqeza* 'whiteness', to gender agreement violations, e.g. **el bondad* 'the$_{Masc}$ goodness' instead of the correct *la bondad* 'the$_{Fem}$ goodness'. Derivational violations elicited an N400+P600, consistent with previous studies, while violations of agreement elicited a LAN+P600 pattern, contrasting the two types of processing, i.e., lexical for derivational violations and grammatical for violations of agreement.

N400-like negativities are the main component elicited by derivational violations in *single-word studies* as well. Two studies using violations of prefixed words (McKinnon et al., 2003; Palmović & Maričić, 2008) produced inconclusive results. For instance, McKinnon et al. (2003) compared lexical decisions to existing English words with a bound stem (*receive*), pseudowords with a bound stem violating English word structure rules (**inceive*), and unstructured pseudowords (**flermuf*). When compared to unstructured pseudowords, both words and pseudowords containing bound stems elicited similar N400 attenuations, supporting morphological decomposition, independently of semantic processing. However, no difference between the two prefixed forms (existing vs violation) was observed. Palmović and Maričić (2008), on the other hand, observed a LAN followed by a P600 for illegal prefix-verb combinations in Croatian (what would be in English **underhold* or **overstand* as opposed to *withhold*/*understand*), and they interpret this as reflecting morphological parsing processes for prefix violations in Croatian. Finally, Leminen et al. (2010), in an auditory LDT with existing derivations vs legal novel derivations in Finnish, obtained N400-like responses for both types of stimuli. However, when compared to illegal derivations (illegal stem-suffix combinations), a larger N400 was observed. Combined, the results of this study suggest decomposition of all complex items and more laborious parsing and licensing for the illegal combinations, as the larger N400 effect suggests. The differences between these three studies could reflect a contrast between the languages under investigation, but they could also reflect differential processing between prefixed vs suffixed derived violations. Specifically, one could claim that prefixed derived words evoke either no effect (McKinnon et al., 2003) or a LAN/P600 pattern (Palmović & Maričić, 2008), but not the N400 component. If this is the case, one could think that EEG studies point towards distinct patterns of processing between prefixed vs suffixed words. However, the scarcity of studies does not allow us to make such strong claims.

Priming studies can usually be summarized as including the following conditions: (A) existing transparent derived words priming their stems (*player* → *play*) compared to (B) pseudo-derived words priming the corresponding stem (*brother* → *broth*)[34] and to (C) orthographically overlapping words with no suffix on the prime e.g. *sandal* → *sand*. Various studies also manipulate semantic transparency as well, such as semi-transparent pairs of the type of *dresser* → *dress* or semantically opaque words, such as *apartment* → *apart*) and compare these to semantically associated word pairs, e.g. *couch* → *sofa*.

With regard to *morphological priming* (condition A above), the results from various studies are broadly consistent in that they all find a reduction of the N400 component on target words preceded by morphologically related primes, e.g. *player* → *play*, relative to unrelated control primes (Kielar & Joanisse, 2011; Lavric et al., 2007; Morris et al., 2007, 2008). Another consistent finding is that in *masked priming*, morphologically related words, as well as identical priming (*table* → *table*), elicit an N250 either alone or in combination with an attenuated N400 (Beyersmann et al., 2014; Holcomb & Grainger, 2006; Morris et al., 2007, 2008, 2011, 2013; Lavric et al., 2007). By contrast, pseudo-derivations of the type *brother* → *broth* (condition B) elicit more diverse effects ranging from no effect (Morris et al., 2007) to N250 attenuations (Morris et al., 2008), and to N250 alongside N400 attenuations (see Morris et al., 2008, 2011, 2013; Lavric et al., 2007).

Comparing the three conditions to each other, the findings are rather inconclusive. For example, Morris et al. (2007) observed significantly more priming by morphologically related words than by either pseudo-derived or form-related words in both the N250 and N400 latency range. However, other studies by Morris et al. (2008, 2011, 2013) found no priming differences between these three types of complexity. Still other studies revealed processing patterns that differed in the early (N250) and the later (N400) effects. The lack of difference in N250 deflections by morphologically

34 For a description of pseudo-derived words, see § 3.2.2

related and pseudo-derived word pairs was taken as evidence that all words undergo the same segmentation process in early visual word recognition. The lack of difference in N400 attenuations between morphologically related and pseudo-derived word pairs was interpreted as indicating a single mechanism with two stages of form-then-meaning processing: orthography-based morphological decomposition followed by semantic interpretation (see Lavric et al., 2011). Finally, similar N400 effects of pseudo-derived and form-related words (Morris et al., 2008, 2011) were interpreted as evidence for a dual-route model that comprises two mechanisms of decomposition: one orthography-based plus one semantically based, hence form-with-meaning (see Morris et al., 2013). The differences could also be linked to different targets across conditions. According to the *Hillyard Principle*, in order to isolate the effects of selective attention one should compare responses to the same physical stimuli while holding other factors like overall arousal and task demands constant. Thus, as Luck (2014: 134) points out, "to avoid sensory confounds, you must compare ERPs elicited by *exactly* the same physical stimuli, varying only the psychological conditions", something which was not the case with any of the above studies.[35]

Studies that employed the unmasked, *overt priming paradigm* complement the above image and our understanding of morphological processing of derived words. In this type of experiment, the primes are overtly perceived and processed at the level of semantics as well. With this in mind, it is not surprising that all studies found attenuated N400 for the condition of morphological priming (*player* → *play*) (e.g. Domínguez et al., 2004; Kielar & Joanisse, 2011; Lavric et al., 2011; Smolka et al., 2015). In the study by Smolka et al. (2015), this was preceded by N250 attenuations.

The picture is slightly more complicated when it comes to the pseudo-derived condition (*brother* → *broth*). Research findings for this condition range from no effect at all (Kielar & Joanisse, 2011) to N400 attenuations for pseudo-derivations (Lavric et al., 2011). In contrast to the pseudo-derivations, orthographically overlapping words (*sandal* → *sand*) usually revealed no substantial effects relative to the unrelated condition (e.g. Kielar & Joanisse, 2011), though an N250 (Smolka et al., 2015) and a N400 attenuation were found as well (Lavric et al., 2011; Smolka et al., 2015).

35 Thanks to Phaedra Royle for bringing this to my attention.

If we look at the above through the perspective of psycholinguistic models of lexical processing, the finding which is the most meaningful is that morphologically transparent words and pseudo-derived words pattern together when it comes to early N400 effects (masked priming) but differ when it comes to late, attenuated N400 effects, pointing towards a two-stage model in which form comes first, followed by processing of meaning. In other words, we first decompose and then we validate semantic information. This would be the prevailing image if Kielar and Joanisse (2011) had not found similar N400 effects for morphologically transparent (*player* → *play*) and semi-transparent words (*dresser* → *dress*), but no effects at all for semantically opaque (*apart* → *apartment*) and pseudo-derived words (*brother* → *broth*). According to them, morphological effects are graded in nature, and they are also modulated by phonological and semantic factors. A point to make here is that their materials were not perfectly matched for various linguistic properties, which may explain the lack of morphological priming (Havas et al., 2012). This is an issue common to many studies, and thus new analysis methods that at least integrate frequency as a random factor might help resolve this issue.

Given the scarcity of studies and the inconsistency of the results, we need to acknowledge that further research is necessary to validate the ERP effects reported thus far and determine whether the combination of N400 and P600 effects is characteristic of violations of derivational morphology across different languages.

4.1.3 EEG studies on compounding

As I showed in Chapter 3, psycholinguistic research on compound processing has brought to light various factors that affect this, such as constituent frequency and length, semantic transparency, relational structure, and headedness. Concerning neuroscientific research, the number of studies dealing with compound processing is considerably smaller than for those dealing with inflection and derivation. In this section, I will review the studies on compounds using EEG. Most of these aim to investigate the above-mentioned critical variables from an ERP perspective and to contribute to our knowledge on compound processing and the stages it involves. As with inflection and derivation, ERP research on compounds is also represented by studies conducted on English, German, Italian, and Dutch, but also on Basque and Chinese. The paradigms include violations (on structural aspects of compounds), the use of novel vs existing compounds, and the specific tasks are priming studies, single-word auditory recognition or production by reading, picture naming, lexical decisions and association tasks.

El Yagoubi et al. (2008) used ERPs to investigate how noun-noun compounds are processed during a visual LDT with Italian speakers, comparing them to non-compounds containing real words and pseudo-morphemes (e.g. *coccodrillo*, 'crocodile', where *cocco* means 'coconut', and *drillo* is not a morpheme). The results showed that RTs and error rates were higher for compounds than for non-compounds and that compounds elicited a more negative peak in the N250 and N400 time windows. These results are compatible with a dual-route model that posits not only whole-word access for compounds but also the activation of decomposed representations of compound constituents. An additional interesting result relates to head position, which in Italian compounds could be on either the left- or the right-hand side of the word (e.g. *CAPObanda*, 'band leader' vs *astroNAVE*, 'spaceship'). While behavioral analysis did not reveal a difference between left- and right-headed compounds, a difference was found with the P300 component. Specifically, right-headed compounds elicited a P300 that continued into a late positivity (300–800 ms) relative to left-headed compounds. The authors interpret this finding as an indication of the role of the compound head as a crucial information-bearing component. Specifically, they suggest that left- and right-headed compounds differ with respect to the attentional resources they require, with right-headed compounds using more resources and eliciting positive components, since they represent the more canonical word order in Italian sentences.

The comparison between semantically transparent vs opaque compounds was the topic of the study conducted by Koester and Schiller (2008). They used a long-lag repetition priming paradigm and compared the effects of transparent compounds (e.g. *eksternest*, 'magpie nest') and opaque compounds (e.g. *eksteroog*, 'magpie eye' = 'corn') on naming a picture of *ekster* 'magpie'. They found equivalent N400 effects for picture naming following transparent and opaque compounds relative to unrelated or form-related primes (e.g. *jasmijn* 'jasmine' priming a picture of *jas* 'coat'). These results suggest morphological priming independently of semantic transparency, and they were interpreted as indicating that morphological priming of a compound facilitates its stem production.

MacGregor and Shtyrov (2013) looked at semantic transparency (transparent vs opaque) and frequency (high vs low), using the oddball paradigm with passive listening. Frequency turned out to be an important factor for *opaque compound* processing, eliciting an enhanced lMMN for frequent compounds compared to low-frequency ones. They took this to reflect stronger lexical representations for high- vs low-frequency opaque compounds. Transparent compounds, on the other hand, showed no frequency effect, nor differed from pseudo-compounds. This was reflected in a reduced sMMN, indexing combinatorial links. The authors argue that transparent compounds are processed combinatorially alongside parallel lexical access of the whole-form representation, but whole-form access is the dominant mechanism for opaque compounds, particularly those of high frequency. The results are in line with a flexible dual-route account of compound processing.

A series of studies compares *novel* to *transparent and to opaque* compounds. By using the repetition priming paradigm, Kaczer et al. (2015) investigated the morphological processing of novel compound words in overt speech production (reading aloud and picture naming). Native speakers of Dutch were instructed to learn novel, non-existing compounds (e.g. *appelgezicht*, 'apple-face') that were later used as primes in a morphological priming task in which the participants had to name the target word. For instance, they were taught the compound *appelgezicht,* which was used for a picture of an apple (in Dutch *appel*). The novel primes were compared with corresponding familiar compounds sharing a free morpheme (e.g. *appelmoes*, 'applesauce') and with unrelated compounds. Clear facilitation of picture naming latencies was obtained when pictures were paired with morphologically related words. Interestingly, the results show that novel compounds had a stronger priming effect than familiar compounds, manifested by shorter naming latencies and a decrease in the N400 amplitude. These results suggest that the participants focus more on the separate constituents when reading novel compounds than in the case of existing ones.

Fiorentino et al. (2014) examined lexicalized, familiar compounds (e.g. *teacup*) and novel compounds (e.g. *tombnote*), comparing them to monomorphemic words and nonwords. They found increased negativities for conditions with compound structure, including effects shared by lexicalized and novel compounds, as well as effects unique to each compound type, which may be related to aspects of morpheme combination. Specifically, they reported broad and long-lasting N400 effects for both lexicalized compounds and monomorphemic words as compared to nonwords, alongside stronger negativity for novel compounds. These findings are interpreted as supporting models for across-the-board morphological decomposition independent of word type.

The association and recollection of compound words versus unrelated word pairs was investigated by Zheng et al. (2015) by using stimuli from Chinese and focusing on the notion of familiarity. That is, the participants had to study and remember existing compounds as an association for a subsequent test.[36] In the testing phase, the participants were instructed to indicate whether the word pair was intact, rearranged, or new (something they had not seen before) by pressing keys on a keyboard. The ERP results showed that compounds evoked a significant early frontal old vs new N400 effect (associated with familiarity for old compounds), which applied to intact compounds but also to compounds with their constituents rearranged. This effect was absent from the unrelated word pairs. In addition, the left parietal old/new N400 effect (associated with recollection) between ERPs to intact and rearranged word pairs was greater for compounds than for unrelated word pairs. These findings suggest that the grouping of constituents enhances the contribution of both familiarity and recollection processes to associative recognition.

In sum, most of the existing cross-linguistic findings (except for English) point towards the role of morphological decomposition in compound recognition and production, confirming the role of frequency and headedness (alongside behavioral experiments), but not providing clear evidence for transparency, contrary to what we know from behavioral studies.

36 In a typical associative recognition task, the participants study unrelated word pairs during an initial study phase (e.g. *umbrella–bread, map–rose, tiger–sand*) and make a distinction between the intact pairs (e.g. *umbrella–bread*) and the rearranged pairs (e.g. *map–sand*) during a subsequent test phase (Zheng et al., 2015).

4.1.4 Interim summary

Most studies on morphological processing using EEG have been conducted in Indo-European languages, mostly English but also Italian, German, French, Dutch, and Spanish. Other languages not belonging to the Indo-European family that have been studied in this way include Finnish, Basque, and Chinese. Typical paradigms used are the violation paradigm and the priming paradigm (masked or overt), as well as reading, passive-listening oddball, and picture naming. All this together constitutes a starting point in the ERP investigations and morphological processing, which is far from exhaustive, both in terms of languages tested and experimental techniques alike. As such, all the obtained results should be treated with caution.

With regard to inflection, and its specific use at the word level (morphophonological processing, see § 4.1.1), the *past-tense debate* has dominated ERP investigations, with fewer studies touching adjectival inflection or other inflectional phenomena. For derivation, most studies investigated stem + affix combinations in words and pseudowords, while compounding studies mainly focused on addressing whether compounds are processed as unitary lexical units or as combinations of constituents. With respect to the main findings, the picture is relatively clear when it comes to the distinction between regular and irregular inflected forms. EEG studies (with the occasional exceptions) report timing differences between the two types of inflected forms, which speak for earlier access to and decomposition of regular inflections than irregular forms. The image is far less clear when it comes to derivation. Most studies suggest that response patterns support decompositional, two-stage (orthographic and semantic) or dual-route accounts, but the latency of morphological effects depends on the specific paradigm. Most of the studies reviewed suggested that decomposition occurs about 200 ms after being presented with the target item (thus affecting the N250) while other studies suggest that significant priming effects can only be found later than this in the subsequent N400. The contribution of EEG studies in relation to compound processing shows that overall and across different languages, morphological decomposition appears to play an important role in compound recognition and production, with headedness and the frequency of constituents mediating this procedure. The role of semantic transparency is less clear, as some studies suggest that it may determine how compounds are accessed, and others claim that transparent and opaque compounds are processed in the same way. Furthermore, there are studies suggesting that the extent to which constituents can be accessed depends highly on the prior experience with the whole compound, supporting differences in the morphological decomposition of novel and existing compounds.

Concerning the role of ERP components, the following very coarse image emerges based on the reviewed studies. While N250s appear to relate mostly to phono-orthographic processing, the LANs are mostly triggered by rule-based processes (illegal combinations), while the retrieval of meaning triggers primarily N400s. In the following section, I will examine the same questions about morphological processing and brain responses by using a more powerful tool, that is, magnetoencephalography. It remains to be seen if results will be consistent with the EEG research or if new insights will emerge.

4.2 Magnetoencephalography

Like EEG, magnetoencephalography (MEG) is a functional imaging technique that directly registers mass electrical activity of neuronal populations and can provide a temporal resolution on the millisecond scale, as well as information about the brain source of components. This allows for the mapping of the neural activation underlying morphological processing online. In addition, MEG has a spatial resolution of approximately 3 mm, due to a high-density coverage with a large number of different sensors (up to 306 channels). It is thus considered a very powerful tool for studying brain responses with respect to morphological processes. Unlike EEG, MEG components do not have negative versus positive polarity. Below, I present the main components that correspond to brain responses after morphologically complex stimuli, and I link them to specific morphological operations. In this background section, I also present the study by Tarkiainen et al. (1999), the earliest MEG study on language, which sets the background for understanding some of the findings discussed later in the chapter.

M170

The M170 is a bilateral neural component that emerges early in the 100–200 ms PSO window, typically peaking around 170 ms PSO. The M170 is primarily generated in the ventral occipitotemporal cortex, specifically in or near the fusiform gyrus and the posterior superior temporal gyrus. It is widely considered to reflect the pre-decomposition stage of morpho-orthographic processing (Zweig & Pylkkänen, 2009). The M170 amplitude is sensitive to several linguistic factors, including stem frequency, affix frequency, and phonological transition probability (TP[37]) (Solomyak & Marantz, 2010; Lewis et al., 2011; Gwilliams et al., 2016; Gwilliams & Marantz, 2018; Neophytou et al., 2018; Stockall et al., 2019; Wray et al., 2022; Cayado et al., 2024). Specifically, there is a positive correlation between TP and the M170 amplitude. That is, the closer TP is to 1, the larger the M170 amplitude. When TP is close to 1, it means that the parser may as well just store the whole letter string as a lemma, since the stem barely exists outside that particular whole word context. The fact that the M170 response is larger for such words lends itself to a coherence or certainty interpretation. Thus, the M170 is larger for stimuli with highly probable or constrained parses, and is smaller where there is more uncertainty, as in the case of entropy (see Linzen et al., 2013, for a discussion).[38]

M350/N400m

The M350 is an MEG component that typically peaks around 350 ms PSO, and it is generated by the left superior temporal cortex (Helenius et al., 1999; Pylkkänen et al., 2002). It is considered one of the earliest MEG components responsive to visual word processing that reflects lexical-level operations. Based on studies in English, it is understood to be the MEG response analogous to the N400, and that is why we also find it referred to in the literature as the N400m. The M350 is sensitive to lexical frequency (Embick et al., 2001) and repetition (Pylkkänen et al., 2002), suggesting its role in lexical access processes. Crucially, however, the M350 does not

37 Phonological transition probability refers to the likelihood of one sound (or phoneme) following another in a language. It is a measure of how frequently a specific sound sequence occurs, and it plays a role in how we perceive and produce speech. Essentially, it is the probability of a particular phoneme appearing given the preceding phoneme.

38 Thanks to Linnaea Stockall for helping me clarify the relationship between TP and the M170 amplitude.

appear to be modulated by interlexical competition, which implies that it occurs at a stage prior to the selection or identification of the best lexical match to the input (Pylkkänen et al., 2004). This relationship was further explored in a study by Pylkkänen et al. (2002), where the participants were presented with stimuli from either dense or sparse similarity neighborhoods – characterized respectively by high and low phonotactic probabilities. Behaviorally, words from dense neighborhoods (high phonotactic probability) elicited slower lexical decision times due to increased lexical competition. However, M350 latencies showed the opposite pattern: high probability/high density stimuli elicited earlier M350 peaks compared to low probability/low density stimuli. This suggests that the M350 reflects an early, facilitatory effect of sublexical factors such as phonotactic probability, prior to the engagement of competitive lexical selection processes. More recently, the M350 has been identified with the lexeme-lookup stage (see § 3.2.2 in Chapter 3 and § 4.2.2 in the current chapter).

Tarkiainen et al. (1999)

The findings of the earliest MEG study on morphological processing, conducted by Tarkiainen et al. (1999), provide a foundational understanding of the neural responses associated with the early stages of visual word processing, which is why I review it here before launching into studies on morphological processing. Tarkiainen et al. (1999) identified two distinct occipitotemporal responses: Type I Response (Early, Non-Specific), which originated bilaterally in the occipital cortex (V2-V4v) and was sensitive to visual properties like noise and string length but not to the linguistic content of the stimuli. This response peaked around 100 ms PSO and is thought to reflect general visual processing mechanisms that apply to both linguistic and non-linguistic visual inputs. The second type of response, i.e. Type II/M170 Response (Later, Letter-Specific), peaked between 130–170 ms PSO and was localized in the left inferior temporal cortex, including regions associated with the Visual Word Form Area VWFA. Unlike the Type I response, the M170 response was sensitive to the linguistic nature of the stimuli, specifically the structural and orthographic features of letter strings. The study is considered pivotal in language-related MEG research, given that it helped researchers establish the methodological viability of MEG for studying the early stages of language processing and also for contributing to the functional characterization of VWFA, an area relevant for morphological processing as well.

4.2.1 MEG studies on inflectional morphology[39]

Studies with MEG are a lot more scarce compared to studies with EEG, given that the use of MEG in language research is relatively new. It is also more expensive than working with ERPs, and it requires a computationally more complex analysis. Most studies investigating inflectional morphology focus on the issue of decomposition, further exploring the *past-tense debate*. Given the excellent time resolution MEG can offer, it allows us to investigate the early stages of lexical activation. One of the first studies on inflectional morphology investigated with MEG was conducted by Stockall and Marantz (2006). They used overt priming on regular (*talk → talked*) and irregular verbs (*gave → give*, *give → gave*), and obtained similar M350 effects. The authors interpreted this result as in favor of full decomposition independently of regularity. A few years later, Fruchter et al. (2013) used masked morphological priming and reported an effect for irregular verbs, as reflected in M170. This provided further support for the decomposition of irregular verbs at an even earlier time window.

Vartiainen et al. (2009) found stronger activation in the left temporal cortex beginning at ~ 200 ms for Finnish inflected nouns compared to monomorphemic ones during silent reading. This effect was independent of word frequency. Moreover, the activation was detected for a long period of time, ranging from 200 to 800 ms after stimulus onset. This resembles an N400m effect, and the authors interpreted it as support for the view that the difference between inflected and monomorphemic words lies at the level of semantics or syntax (and thus later operations) and not at the decomposition level. This was also supported by the absence of an earlier effect of morphology, such as an M170-like response.

Important insights come from auditory studies that aimed to provide an answer to the issue of the time course of morphological decomposition.

39 I will keep the same order of presentation, that is, first studies on inflectional morphology, then on derivational morphology, then on compounding for the sake of uniformity with other sections. As will become obvious, in MEG research, due to the nature of the specific research questions, the distinction between the three, especially between inflection and derivation, appears to be less relevant.

Auditory tasks have the advantage of being able to track processing as the stimulus unfolds. Passive listening paradigms are especially informative in revealing the automatic processes involved in morphological decomposition, since they are free from attentional and strategic effects, and are specific to linguistic information (Hanna et al., 2016). The *past-tense debate* was the topic of the study by Bakker et al. (2013), who used the oddball paradigm. They compared monomorphemic words (*hide*), pseudowords (**smide*), regular past-tense forms (*cried*), and ungrammatical (overregularized) past-tense forms (**flied*). They found an enhanced lMMN to monomorphemic words relative to pseudowords, but a reduced sMMN to ungrammatically inflected past-tense forms relative to grammatical ones. This dissociation between responses to monomorphemic and bimorphemic stimuli indicates that regular past tenses are processed more similarly to syntactic structures than to lexically stored monomorphemic words, suggesting that regular past tenses are generated productively by the application of a combinatorial scheme to their separately represented stems and affixes. Additional support for this finding was provided by another study, which used a similar paradigm (Whiting et al., 2013). They showed that passive listening of English verbal and nominal inflections yielded early activation (135 ms POS) at the left fronto-temporal region compared to non-affixed words.

The same kind of early activation (100–200 ms) was also found in an active listening task with grammaticality judgments (Leminen et al., 2011) comparing inflected, derived, and monomorphemic words. An early ~100 ms activation was observed for both inflected and derived words, and it was interpreted to reflect lexical access to a suffix, irrespective of its category (inflection vs derivation). In a later window (~200 ms), a larger left-lateralized component was observed for inflected words only as compared to derived and monomorphemic words. This was taken to reflect the analysis of the base and suffix, and, possibly, (morpho)syntactic feature checking of the morpheme combination.

Finally, two studies by Wray et al. (2022) and Cayado et al. (2024) investigated visual word recognition of Tagalog complex words. Wray et al. (2022) included items created by reduplication, infixation, and circumfixation. They were a mix of derivations and inflections. In a lexical decision task with MEG, they found that VWFA activity correlates with stem:word

TP for circumfixed, infixed, and reduplicated words, independently of inflection vs derivation. The focus of the study by Cayado et al. (2024) was on inflectional prefixes, intending to investigate the contribution of syntactic information during the *recombination stage* (see § 3.2.2 and § 4.2.2 below), where both syntactic and semantic information are expected to be analyzed. Their results replicated previous findings implicating the left fusiform gyrus in the decomposition of complex words into their constituent parts. Additionally, they showed that the recombination stage engages the left posterior temporal lobe and left orbitofrontal cortex (something which was already known for derived words, see § 4.2.2). The main contribution of the study is that it demonstrated that inflected words share the same core processing signature as derived words during the early decomposition stage. However, during recombination, inflected words are processed more rapidly compared to derived words. I will revisit these issues through the investigation of derivational morphology as well, as it offers more fertile ground with respect to the processing of meaning.

4.2.2 MEG studies on derivational morphology

The main motivation behind the earlier studies that used MEG to investigate derivational morphology was to explore the timing of morphological decomposition, through an additional morphological operation, and to complement the findings based on inflection. More specifically, researchers focused on the M170 component and its role in reflecting early decomposition, but also the M350 component and its role in subsequent semantic processes. More recent studies focus more on the exploration of post-decomposition processes. The studies I will present revolve around three axes: (1) relating morphological decomposition to VWFA (Zweig & Pylkkänen, 2009; Gwilliams et al., 2016), (2) relating the M170 to stem:whole word TP (Solomyak & Marantz, 2010; Lewis et al. 2011; Lehtonen et al., 2011), and (3) relating the M350 to composition/interpretation (Bölte et al., 2010; Neophytou et al., 2018; Stockall et al., 2019). These studies offer varying results, supporting either the full decomposition or the dual-route model of lexical access. Most of the earlier studies that used MEG to investigate derivational morphology deal with English. In recent years, however, understudied and non-Indo-European languages have entered the world of neuroimaging investigations using MEG.

Building on Tarkaianen et al. (1999), Zweig and Pylkkänen (2009) compared the processing of morphologically complex words like *teacher* and *refill*, with the processing of monomorphemic words like *stretch* and *throng*. They found a significant increase in activity peaking ~170 ms PSO for the morphologically complex words, which they identified as the M170 response. The prefix effect was bilateral, but the suffix effect was found only in the right VWFA. The authors argue that this finding reflects precisely the early stage of visual-word-form-based morphological segmentation, also described in behavioral masked morphological priming experiments.

The earlier work by Tarkiainen et al. (1999) was also revisited by Gwilliams et al. (2016), who provided a more detailed account of the temporal and spatial aspects of the occipitotemporal responses involved in visual word processing. By using an analysis which allows for more refined spatial resolution compared to the one used in the original study, they were able to offer a nuanced view of the Type II response, allowing them to decompose it into two distinct components: The first was a Type II-Noise Response, describing a posterior, negative polarity, peaking at ~130 ms PSO that was modulated by the complexity of the visual properties of the stimulus, but still sensitive to some aspects of orthographic structure. The second was Type II-Letter Response describing an anterior, positive polarity, peaking at about ~170 ms PSO, that was found to be modulated specifically by the morphological features of the stimuli, reflecting a more abstract level of linguistic processing, involving morpho-orthographic or morpho-lexical decomposition. By distinguishing these two responses, Gwilliams et al. (2016) provided crucial insights into the stages of visual word processing. Their results suggest that early orthographic processing occurs in the posterior regions of the occipitotemporal cortex, while more anterior regions are recruited for processing morphological structure.

An interesting dimension was brought to light by Solomyak and Marantz (2010) and Lewis et al. (2011). That is, they showed that the magnitude of the M170 response is correlated with the stem:whole-word TP of a potentially morphologically complex word. Words with low TPs such as *taxable* are associated with smaller M170 amplitudes than words with higher TPs such as *tolerable*. Solomyak and Marantz (2010) showed that while the M170 response is sensitive to morphological TP and affix frequency, it is not modulated by orthographic form features such as string frequency and bigram TP. The orthographic properties of words, such as the positional letter frequency of the affix and the TP from the last letters of the stem to the first letters of the affix, were found to modulate brain activity around 130 ms, but had no effect on the later M170.

Lewis et al. (2011) investigated pseudo-derived items (e.g. *brother*, see § 3.2.2). They found that pseudo-stem:whole-word TP also significantly modulated M170 activity for these words, a finding which is consistent with the evidence from the masked priming experiments. They also found that the surface form frequency of these words modulates the M170, providing some support for dual-route recognition for words for which decomposition creates a garden path.[40] The authors conclude that decomposition is obligatory and based on statistical relations between stems and affixes, and that whole word representations may be available early in word visual word recognition, but only for those words whose decomposition does not lead to recognition in the mental lexicon, such as pseudo-derived words. Another contribution by Lewis et al. (2011) is that they showed that the posterior portions of the fusiform gyrus were affected by orthographic properties of the stimulus, whereas the more anterior portions were modulated by morphological properties of the stimulus, i.e., the presence of a morpheme-like unit.

An additional study providing support for dual-route access was conducted by Lehtonen et al. (2011). They used masked priming to examine the neural dynamics of morphological processing, and they identified a left occipitotemporal response occurring around 220 ms PSO, resembling the M170 response. This early neural activity was sensitive to the morphological relationship between primes and targets but was not modulated by semantic transparency. This suggests that the response reflects a prelexical level of processing, where the brain is sensitive to morphological structure before fully accessing semantic information. An interesting finding from this study is that semantically opaque words with high TP

40 A garden path is a type of sentence that initially leads the reader or listener to interpret it in one way but then forces a reanalysis when the structure turns out to be different than expected. In the morphological processing literature, a garden path refers to erroneous decomposition, i.e. *corner* is not *corn* + *-er*. Once the processor realizes that decomposition leads to the wrong path of interpretation, it reanalyzes the word and processes it as non-decomposable.

did not show significant priming effects, either behaviorally or in MEG responses. This result was interpreted as supporting dual-route models of morphological processing, as it points out the key role of frequency and semantic transparency in determining whether morphological decomposition occurs early in processing.

Bölte et al. (2010) moved the focus from decomposition to interpretation, as they looked at how morphologically complex words are interpreted, rather than how they are decomposed. Their findings suggest that during derivation processing, the brain actively engages in decomposing word forms and assessing their morphological legality, but also their semantic plausibility. Specifically, they used an unprimed synonym judgment task to investigate the neural processing of derived adjectives in German. They compared three types of stimuli: existing derived adjectives (e.g. *freundlich* 'friendly'), non-existing but semantically legal derived adjectives (e.g. *freundhaft* – a plausible, though non-existent, derivative meaning 'friend-like'), and non-existing semantically as well as morphologically illegal adjectives (e.g. *freundbar* – a form that is both semantically nonsensical and morphologically impossible). Their findings showed a gradual increase in activity in the left temporal lobe during the N400m time window, whose magnitude increased progressively from existing, to semantically legal, to semantically and morphologically illegal adjectives. This was interpreted as reflecting either the *semantic interpretation* of the derived forms, with more processing effort required as the forms deviate from semantic expectations (illegal forms being the most difficult to process) or *morphological integration* of the decomposed morphemes, where the brain attempts to combine morphemes into a meaningful whole, with illegal forms triggering more neural effort due to their implausibility. In either case, their results highlight the role of semantic integration in derived words.

The MEG investigations of Neophytou et al. (2018) and Stockall et al. (2019) primarily focus on post-decomposition morphological processes. The distinction between *licensing* and *recombination* (see § 3.2.2) was investigated by Neophytou et al. (2018) by using Greek suffixed pseudowords and by Stockall et al. (2019) by using English prefixed pseudowords. Both studies provided converging evidence that syntactic licensing of stem-suffix combinations and semantic composition of the same combinations differentiate both in temporal as well as in spatial terms. Specifically, both studies found larger amplitudes for pseudowords violating the syntactic category of the stem (*karekla+tis* 'chair-er'; **re+happy*) in the temporal lobe from 200–300 ms (corresponding to syntactic *licensing* errors) compared to larger amplitudes for argument structure violations (**orimas-tis* 'mature-er'; **re+dance*) items in orbitofrontal cortex, between 300–500 ms (corresponding to *recombination* difficulties).

Finally, the study by Wray et al. (2022), also described in § 4.2.1, contributes significantly to our understanding of how various types of morphological structures – such as reduplication, infixation, and circumfixation – are processed in the brain. They used stimuli from Tagalog to show that the above morphological processes are comparable to prefixation and suffixation in terms of being automatically parsed by the ventral visual stream during word recognition. This supports the idea that morphological decomposition is a general feature of the visual word form system. Another important finding of the study is the correlation between stem:word TPs and activity in the VWFA, which further highlights the key role of this region in parsing morphologically complex words, regardless of the specific type of morphological operation involved.

4.2.3 MEG studies on compounding

Only a handful of studies have used MEG to investigate compound processing. Two of them are on English (Fiorentino & Poeppel, 2007; Brooks & Cid de Garcia, 2015), one uses Chinese materials (Hsu et al., 2019), and one uses Japanese materials (Egashira et al., 2022).

Fiorentino and Poeppel (2007) provide important insights into the neural processing of compound words using MEG in a visual LDT. They compared compound words (e.g. *flagship*) to monomorphemic words (e.g. *crescent*), and to pseudo-morphemic controls (e.g. *crowskep*, which appear to be morphologically complex but are not). Compound words elicited a significantly earlier M350 peak latency compared to monomorphemic words, suggesting that compound words are processed through morphological decomposition, in which their constituent morphemes are rapidly parsed early in processing. This early processing was associated with activation in temporal regions, a finding that aligns with the broader literature on morphological decomposition. The fact that the pseudo-morphemic controls did not show a significant difference from compound words in terms of M350 latency suggests that these non-words, which mimic the structure of compounds, may also be processed as if they were compound words. This indicates that early morphological parsing mechanisms are likely triggered by structural cues, regardless of the actual lexical status of the word. Thus, the study provides support for early morphological parsing in compound processing, highlighting the brain's sensitivity to the internal structure of morphologically complex words.

Brooks and Cid de Garcia (2015) expanded on transparency in compound processing by investigating how both transparent compounds (e.g. *roadside*) and opaque compounds (e.g. *butterfly*) are processed in comparison to morphologically simple words (e.g. *spinach*) using a word naming task with priming. Their study employed partial-repetition priming, where the first constituent of the compound served as the prime (e.g. *tea* for *teacup*), and in the case of simple words, a pseudo-morphologically related form was used (e.g. *spin* for *spinach*). They also included control conditions with unrelated primes (e.g. *doorbell* → *teacup*) and full-repetition priming (e.g. *teacup* → *teacup*). The results of their analysis revealed two significant neural clusters when comparing transparent compounds (*teacup*) to monomorphemic words (*spinach*). The first one was localized to the anterior middle temporal gyrus (MTG), which was active between 250–470 ms. This cluster likely reflects a stage of morphological decomposition that is independent of semantic meaning, as it was associated only with morphologically transparent forms. The second cluster was localized to the posterior superior temporal gyrus (STG), and it was active between 430–600 ms. This may represent a compositional stage where semantic integration takes place, again only for transparent compounds. The two clusters together suggest that after morphological decomposition occurs, there is a separate processing stage where the meaning of the word is composed or integrated from its morphemic parts. Interestingly, the study did not report significant differences between opaque compounds and monomorphemic words.

The two studies with non-English stimuli offered important insights with respect to morphological processing and brain activity. Specifically, Hsu et al. (2019) used MEG in a visual lexical decision to record brain activity during the reading of four types of Chinese disyllabic words with two characters: (1) monomorphemic disyllabic words (e.g. *qiū yǐn,* 'earthworms'), serving as the baseline condition; (2) coordinative compounds (e.g. *huā cǎo*, 'flower-grass' meaning 'plants'), which are double-headed, with meanings derived jointly from both constituents; (3) modifier-head compounds (e.g. *qì chē*, 'gas-car' meaning 'automobile'), which are right-headed, with the first morpheme modifying the second; and (4) verb-object compounds (e.g. *kāi chē*, 'operate-car' meaning 'to drive a car'), in which the first and second morphemes denote an action and its object, respectively. Source localization analysis revealed that at approximately 200 ms after word onset, compound words elicited greater activation in the left anterior temporal cortex compared to monomorphemic words, potentially reflecting early morphological decomposition processes. Between 300 and 400 ms, modifier-head and verb-object compounds elicited significantly increased activity in the left posterior temporal cortex, relative to monomorphemic words. In contrast, coordinative compounds did not show a significant difference from monomorphemic words during this time window. These findings suggest that both morphological complexity and internal compound structure modulate neural activity in the left temporal cortex during the reading of disyllabic Chinese words.

4.2.4 Interim summary

The use of MEG in morphological investigations has shed light on various issues that occupied researchers working on morphological processing. Taken together, the studies on inflection using MEG have shown evidence for morphological decomposition. Early studies (e.g. Stockall & Marantz, 2006; Fruchter et al., 2013) supported morphological decomposition for both regular and irregular verbs, with early MEG components (M170, M350). The findings from silent reading (e.g. Vartiainen et al., 2009) suggest later semantic/syntactic processing differences between inflected and monomorphemic words rather than early decomposition effects. Moreover, auditory MEG studies (e.g. Bakker et al., 2013; Leminen et al., 2011) show early activation earlier than 250 ms POS for inflected forms in the left fronto-temporal cortex and support productive morphological processing. Recent work (e.g. Wray et al., 2022; Cayado et al., 2024) highlights shared early decomposition processes for inflection and derivation, but faster recombination for inflectional morphology.

Early MEG research on derivational morphology established the role of M170 as linked to early morpho-orthographic segmentation and the role of M350 as associated with subsequent semantic interpretation. Zweig and Pylkkänen (2009) demonstrated M170 sensitivity to morphologically complex words in the VWFA, while Gwilliams et al. (2016) refined this work by distinguishing between early orthographic and morpho-lexical responses in the occipitotemporal cortex. Solomyak and Marantz (2010) and Lewis et al. (2011) further established that the M170 is modulated by stem-to-whole-word TPs, rather than by surface orthographic features, and that pseudo-derived words also trigger decomposition. A shift in focus from decomposition to interpretation was introduced by Bölte et al. (2010), whose findings revealed that semantic plausibility and morphological legality modulate activity in the N400m time window. Neophytou et al. (2018) and Stockall et al. (2019) built on this by showing that syntactic licensing and semantic recombination occur at distinct temporal and spatial stages in the brain.

A relevant point to make here is that while in studies dealing with inflection the decomposition route was a stable finding, there is some variability in the results concerning derivational morphology. This could stem from the heterogeneous nature of derivational processes compared to inflection (see Chapter 1, § 1.4 and Leminen et al., 2019 for a discussion). Unlike inflections, which tend to follow more systematic grammatical rules, derivations often introduce significant changes to the meaning and syntactic category of a word, making them more complex and potentially engaging multiple neural processes over varying time courses. While behavioral studies have mostly shown early, obligatory decomposition for both inflections and derivations, the neural evidence for derivations is less uniform. MEG studies contribute to this discussion by providing precise temporal insights, but the range of findings indicates that derivational morphology might involve a more flexible set of processes than inflection, influenced by lexical, semantic, typological and morphosyntactic factors. This ongoing discrepancy points to the need for more nuanced interpretations and further research to clarify how different types of derivations are processed and whether the timing of morphological parsing varies depending on the specific linguistic and cognitive demands of the derivational morphemes involved.

Finally, MEG research on compound word processing is limited, with only a few studies conducted across English, Chinese, and Japanese. Fiorentino and Poeppel (2007) found that compound words elicited earlier M350 responses than monomorphemic words, suggesting rapid morphological decomposition. Brooks and Cid de Garcia (2015) showed that transparent compounds (e.g. *teacup*) activated the anterior MTG (250–470 ms) and posterior STG (430–600 ms), reflecting morphological decomposition and semantic integration, while opaque compounds (e.g. *butterfly*) did not differ from monomorphemic words. Hsu et al. (2019), using Chinese stimuli, found that compound structures modulate left temporal cortex activity depending on internal structure, with modifier-head and verb-object compounds showing distinct effects. Egashira et al. (2022) showed that Japanese kanji compounds activate fusiform-adjacent areas only when lexically meaningful, while early visual deviations (e.g. font) are processed in the occipital pole. These studies collectively highlight language-specific patterns and the importance of both form and meaning in compound word processing.

Apart from the temporal dimension, which has advanced our knowledge compared to EEG studies, MEG research makes specific claims about the spatial organization of morphological operations. Based on the studies reviewed here, it seems that early decomposition processes localize to the ventral occipitotemporal cortex, particularly the VWFA. Posterior regions of the fusiform gyrus appear to be sensitive to low-level orthographic features (~130 ms), and more anterior fusiform regions respond to morpholexical structure, while left occipitotemporal activation reflects morphological relationships, even in the absence of semantic transparency. At the same time, later stages of processing shift to the temporal and frontal lobes.

The following section will focus exclusively on the localization of morphological processing in the brain, aiming to explain whether the morphological processes under investigation have their correlates in brain activation, and which brain regions might undertake them.

4.3 Functional imaging and other neuroimaging techniques

The use of functional imaging in language research primarily focuses on *where* certain operations take place in the brain. Functional neuroimaging studies have greatly expanded our knowledge of the brain systems supporting language, producing a dramatic reawakening of interest in this topic and a substantial revision of the classical neuroanatomical model formulated by Broca, Wernicke, and others. As will become evident in the following sections, functional imaging has been instrumental in revealing that proposed linguistic operations – such as the rule-based decomposition of regularly inflected forms – are associated with distinct patterns of brain activation, and in identifying the brain regions likely responsible for carrying them out.

4.3.1 fMRI studies on inflectional morphology

With regard to inflectional morphology, most fMRI studies have focused on the processing of English verbal inflections related to the *past-tense debate* and the differences between regular and irregular inflection, while fewer studies have looked at nominal inflections. These studies consistently revealed that both regular and irregular inflections engage an extended left-hemisphere network, including temporal and parahippocampal regions. However, when directly comparing the two forms of inflection, regular inflection appears to activate additional brain regions, such as the left inferior frontal gyrus (LIFG) and related frontal regions like the middle frontal gyrus (MFG), the basal ganglia, and the cerebellum. These areas are often implicated in rule-based processing and may reflect the application of grammatical rules in generating regular past-tense forms. This is consistent with dual-route models that posit that regular forms are processed via rule-based mechanisms, whereas irregular forms rely more on memory retrieval. Some of the key studies contributing to that are briefly presented here.

For instance, Bozic et al. (2010, 2015) used inflected (e.g. *prayed*) vs monomorphemic, not overtly inflected (e.g. *dream*) stimuli from English in two auditory tasks, which consistently highlighted the role of the LIFG and its subcomponents in regular inflection, suggesting a reliance on rule application. Furthermore, Davis et al. (2004) and Sahin et al. (2006) found that regular forms activate not only the frontal regions but also the basal ganglia and cerebellum, reflecting the broader network involved in processing rule-governed morphological structures. Finally, Joanisse and Seidenberg (2005) and Pliatsikas et al. (2014) provide additional evidence supporting the role of basal ganglia and LIFG in regular inflection, which may represent a combinatorial system involved in applying morphological rules.

For *irregular inflections*, which are expected to be processed more through lexical retrieval than rule application, fMRI studies have shown less consistent activation patterns. However, temporal, parietal, and parahippocampal regions are often linked with irregular inflection, reflecting the involvement of semantic memory and lexical retrieval. Specifically, some studies (e.g. Tyler et al., 2004; Sahin et al., 2006) found that irregular forms rely more heavily on semantic processing areas, although this activation is less robust and less consistent than that for regular inflection.

Interestingly, these activation patterns have also been observed in studies on plural formation for nouns, where regular plural forms seem to activate similar networks as regular past tense inflection, particularly involving LIFG and basal ganglia (Bozic et al., 2015; Sahin et al., 2006). German, a language morphologically related to English, shows similar patterns of neural activation for regular and irregular inflection (e.g. Beretta et al., 2003; Prehn et al., 2018). These studies suggest that the neural mechanisms for processing regular and irregular forms may be somewhat universal across languages with similar morphological systems. Overall, these findings support the idea that regular inflection relies more on rule-based processing mechanisms, engaging areas like the LIFG and basal ganglia, whereas irregular forms may rely more on lexical retrieval from temporal and parahippocampal areas. This distinction aligns with dual-route models of morphological processing, where regular forms are computed via rules and irregular forms are retrieved from memory.

If one goes beyond English (or Germanic languages), studies on inflectional morphology and fMRI are scarce, with mixed findings. For instance, in Italian (Marangolo et al., 2006), inflected forms engage distinct neural circuits depending on the grammatical category of the word. That is, inflected verbs activate the LIFG, while inflected adjectives engage the left precentral, left angular, and bilateral middle occipital gyri, and inflected nouns activate the left insula and several right hemisphere regions. This suggests that the neural processing of inflected words in Italian is sensitive to grammatical category, potentially reflecting different pathways for verb, adjective, and noun morphology.

In Spanish, De Diego-Balaguer et al. (2006) found that regular verbs activate left temporal and hippocampal regions, while irregular verbs engage bilateral frontal regions and show LIFG involvement. This opposite pattern of regular-irregular processing in Spanish, where irregular verbs engage a broader bilateral frontal network and regular verbs are linked to left temporal areas, contrasts with findings in Germanic languages, where regular inflection typically activates LIFG, and irregular forms engage temporal regions. Studies conducted in Russian generally show similar activation patterns for both regular and irregular verbs, with some researchers suggesting that morphologically complex forms are always decomposed, regardless of their regularity. For instance, Kireev et al. (2015) and Slioussar et al. (2014) found evidence that Russian verbs are decomposed into their morphemes consistently, irrespective of whether they are regular or irregular, and irrespective of whether they are real or nonce. That is, they found that the set of brain regions influenced by regularity largely (regular vs irregular) overlaps with the one influenced by Lexicality (existing vs nonce), and this area includes the fronto-parietal brain network comprising the inferior frontal gyrus and the inferior/superior parietal lobule of the left hemisphere. This contrasts with languages like English, where irregular forms are often retrieved as whole, and points to a potential cross-linguistic difference in how morphologically complex words are processed.

In Finnish, Lehtonen et al. (2006, 2009) showed that regular inflections activate both left frontal and temporal regions, while a similar comparison in Japanese revealed activation in the left premotor area alongside the LIFG (Yokoyama et al., 2006). This shows consistency in frontal involvement but suggests language-specific variations in the neural circuits supporting regular inflection processing. Interestingly, in Polish, a Slavic language, there were no consistent findings for inflection processing compared to an acoustic baseline (Szlachta et al., 2012). The LIFG and bilateral temporal regions were only activated when inflected forms were contrasted with baseline stimuli, suggesting morphologically complex words in Polish might engage different neural resources or be processed similarly to simpler word forms. Finally, Swedish provides a challenging view with regard to the assumption that all morphologically complex forms are subject to automatic decomposition across languages. Lehtonen et al. (2009) found no differences in the activation patterns between inflected and simple words, which suggests that morphologically complex forms might be processed as whole words, without the typical activation patterns seen for morphological decomposition.

Taken together, these cross-linguistic findings highlight the diversity in the neural processing of inflectional morphology. While left hemisphere structures such as the LIFG are frequently involved in morphological processing across languages, the specific neural networks engaged can vary depending on language typology, grammatical categories, and inflectional complexity. Some languages, like Russian, appear to favor decomposition even for irregular forms, while others, like Swedish, may process complex forms as whole words. In a comparison with MEG data, which were more or less consistent concerning inflectional morphology, the fMRI revealed a considerable variation. In the following section, I will explore patterns of activation in relation to derivational morphology, an area for which variability is already known by EEG and MEG studies.

4.3.2 fMRI studies on derivational morphology

A substantial body of fMRI studies has explored the neural processing of *derivation*, seeking to understand how the brain handles morphologically complex words. This literature addresses several key issues. One of them is the obvious question of the *localization of derivation* in the brain. Many studies aim to determine whether derivation is a grammatical operation that, like inflection, can be localized to specific brain regions. The focus has often been on whether derivation engages distinct neural circuits compared to those involved in different kinds of processing. A second issue pertains to the comparison between *whole-word* and *decompositional* processing, that is, whether derived forms are processed as single-word units or as morphologically complex units. Finally, a third issue concerns the role of various *lexical properties* (semantic transparency, frequency, etc.), which likely mediate derivational processing. Like inflection, most studies have been conducted in English, employing mainly derived nouns and, to a lesser extent, verbs and adjectives.

The first published fMRI study on derivational morphology, conducted by Davis et al. (2004),[41] addressed the question of decomposition or not. Their results suggested that derived words (*cheerful*) do not elicit different patterns of brain activation compared to monomorphemic words (*monarch*). This early finding implied that the brain might process derived words similarly to monomorphemic ones, potentially treating them as whole units rather than as morphologically complex forms. Similarly, Devlin et al. (2004) used a masked priming paradigm and provided evidence that morphological processing may not be a distinct or independent cognitive operation. Their study found that derivational pairs (*hunter → hunt*) activated temporal and parietal regions, like those activated by word pairs with orthographic (*passive → pass*) and semantic (*sofa → couch*) relationships. This overlap in activation was interpreted as suggesting that morphology might emerge from the interaction of form (orthography) and meaning (semantics), rather than being processed through a specialized, standalone morphological mechanism in the brain. At the same time, Bozic et al. (2007) found clear evidence for morphological decomposition, demonstrated by increased activity in the LIFG during the processing of either transparent (*bravely → brave*) or opaque (*archer → arch*) derived forms, as opposed to identity priming (*mist → mist*) and priming for pairs of words that shared only form (*scandal → scan*) or meaning (*accuse → blame*).

Finally, the study by Gold and Rastle (2007) further contributes to the controversial image, providing evidence that derivational processing may be heavily influenced by orthography. In a masked priming study, they found a reduction in brain activity in occipital regions for word pairs containing pseudo-derivations (*brother → broth*) and for pairs with orthographic overlap (*brothel → broth*) compared to unrelated controls. This suggests that morphological decomposition is at least partly mediated by orthographic similarity, implying that the visual form of words plays a significant role in how the brain processes derivations. In these cases, the brain appears to rely on surface form cues rather than purely morphological rules.

41 The study also included inflected items, see § 4.3.1

Around the same time, a different group of studies began looking at the role of different lexical properties that might affect the processing route. Two studies by Vannest et al. (2005, 2007) showed that suffix productivity and base form frequency influence the processing of derived words. Vannest et al. (2005) found that derivations with highly productive suffixes (e.g. -*ness*) elicited increased activation in Broca's area and the basal ganglia compared to derivations with less productive suffixes (e.g. -*ity*). This pattern suggests that morphological decomposition is more likely for words with productive suffixes, while whole-word processing may dominate for less productive ones. In a follow-up study, Vannest et al. (2011) proposed that the effects reported in their previous study might also be modulated by the frequency of the base form of the derived form. Specifically, they suggested that high-frequency base forms might facilitate whole-word processing even for derivations with productive suffixes. Similarly, Blumenthal-Dramé et al. (2017) emphasized the role of base frequency in modulating whether derivational forms are processed via decomposition or as stored lexical entries.

The common point of all the above studies is that they were conducted in English. When one goes beyond English, however, a slightly different pattern emerges. Two masked priming studies in Hebrew have provided compelling evidence for morphological processing that is independent of orthographic form and semantic meaning. For example, Bick et al. (2010; 2011) found that morphologically related word pairs elicited reduced brain activity in bilateral frontal, temporal, and parietal regions compared to orthographic or semantic pairs. This reduction suggests that Hebrew speakers engage in a morphological decomposition process that is distinct from both form-based and meaning-based processing. These findings are further supported by Bick et al. (2008), who reported similar evidence using a different morphological priming task. Collectively, these studies highlight that, at least in Hebrew, the morphological relationships between words can be processed independently of their surface forms or semantic content, pointing to a more abstract level of morphological analysis. This evidence contrasts with findings in English, where the debate over whether derivational forms are processed as decomposed or whole words is still ongoing, emphasizing the possibility of cross-linguistic differences in how morphological structures are processed in the brain.

Two studies conducted in Italian (Carota et al., 2016; Marangolo et al., 2006) also support decomposition, with compelling evidence that derivations are processed as decomposable forms. For instance, Carota et al. (2016) used passive listening, and they found bilateral fronto-temporal activity for opaque forms with non-productive suffixes (*ventura* 'destiny') compared to transparent words with productive suffixes (*pineta* 'pine forest'), which showed stronger activation in the LIFG, clearly dissociating the two. These findings align with those from research in Dutch (De Grauwe et al., 2014) with transparent prefixed verbs, which also suggests that derivational forms undergo decompositional processes during recognition.

In contrast, studies involving Slavic languages like Polish (Bozic et al., 2013) and Russian (Klimovich-Gray et al., 2017) present a different perspective. Bozic et al. (2013) used (1) semantically transparent derived nouns, e.g. *pudełko*, 'little box'; (2) semantically opaque derived nouns, e.g. *kanapka*, 'sandwich'; and (3) simple nouns, e.g. *kapusta*, 'cabbage'. They found no differences among conditions in activation in the LIFG, which would signal decomposition for the transparent items. The evidence from these languages indicates a tendency toward whole-word processing of derivations, suggesting that the morphological structure may not be as salient or influential in the recognition of these forms as it is in languages like Italian and Dutch.

A plausible explanation for these language-specific effects lies in the distinct lexical properties across languages, which include factors such as *semantic transparency*, *suffix productivity*, and *base frequency* among related forms. These properties can differentially influence how derivations are represented neurally in various languages. A related point which needs to be taken into account is various task effects. The majority of studies reviewed here used the priming paradigm and to a lesser extent the passive listening paradigm. These two tasks tap into distinct cognitive processes, which may interfere with the patterns of activation. Finally, the variability of the results could also be explained by typological differences among the languages under investigation. Concatenative morphology languages (Hebrew) provided a clear pattern of data. Data from fusional languages are characterized by greater variability. All this together highlights the necessity of considering a variety of factors when examining morphological processing across different languages. The variability in processing strategies underscores the complexity of language and the adaptive nature of cognitive mechanisms in response to the linguistic environment. The existing evidence makes it clear that the question of how derivational morphology is processed remains unresolved.

4.3.3 fMRI studies on compounding

The literature on the processing of compounds using fMRI is relatively sparse, encompassing only a few studies that employ various methods and address different research questions. One of the earliest studies in this domain was conducted by Koester & Schiller (2011) in Dutch. This study found increased activation in the LIFG when the first part of a compound served as a prime for a picture, compared to conditions where unrelated primes were used. Notably, this activation occurred regardless of the semantic transparency of the compound, suggesting that the processing of compounds in Dutch involves an automatic and default mechanism of decomposition.

Expanding on the existing literature, Forgács et al. (2012) investigated the processing of known compounds in German and found increased bilateral activation in the frontal and temporal regions when compared to novel but phonologically valid compounds. Interestingly, the latter resulted in heightened activation specifically in the LIFG. The authors interpreted these findings as indicative of distinct processing strategies: known compounds likely engage semantic processing based on established representations, while novel compounds necessitate a more active integration of phonological, syntactic, and semantic information from both components to construct meaning.

More recently, Zou et al. (2016) explored compound processing in Chinese, using various types of compound pairs categorized by their relationships: (a) identical, (b) phonologically related, (c) phonologically and orthographically related, and (d) phonologically, orthographically, and morphologically related. Their findings revealed that all types of compound pairs activated the LIFG, with the level of activation being modulated by the degree of relatedness between the compounds. In particular, the highest activation occurred for pairs that were related on all three levels (phonological, orthographic, and morphological).

The limited number of fMRI studies on compound processing suggests involvement of LIFG. At the same time, it underscores the difficulty in drawing definitive conclusions about underlying neural mechanisms. The variety of tasks across languages and types of compounds further highlights the necessity for more extensive research in this area to better understand the complexities of compound processing in different linguistic contexts. Future studies should aim to explore these dynamics more thoroughly, as they could provide valuable insights into the cognitive and neural processes involved in morphological analysis across languages.

4.3.4 Interim summary

The use of functional imaging in morphological processing offers significant insights into the processing of inflectional and, to some extent, derivational morphology, but the number of studies on compounding is small, and the findings should be interpreted with caution.

With respect to inflectional morphology, fMRI research consistently reveals that both regular and irregular inflections engage an extended left-hemisphere network, which includes temporal and parahippocampal regions. However, when directly comparing the two forms of inflection, regular inflection appears to activate additional brain regions, such as the LIFG and related frontal regions like the MFG, as well as the basal ganglia and cerebellum. The activation of these areas is often associated with rule-based processing, suggesting that the brain applies grammatical rules when generating regular past-tense forms. This implies that the neural mechanisms for processing regular inflections might involve more complex cognitive operations than those for irregular forms, which may be processed more as memorized items. Future research could further explore the implications of these findings for models of morphological processing, particularly in understanding the interplay between lexical retrieval and grammatical rule application across different languages and morphological structures.

A substantial body of fMRI research has examined how the brain processes derivational morphology, but the findings remain mixed. Early studies in English suggested that derived words may be processed similarly to monomorphemic ones, both activating temporal and parietal regions, without engaging a distinct morphological system. However, other studies found evidence for morphological decomposition and clear LIFG involvement, at times being shaped by orthographic overlap and the involvement of occipital areas. Lexical factors such as suffix productivity and base frequency also modulate processing strategies, with more productive suffixes favoring decomposition (Vannest et al., 2005, 2007; Blumenthal-Dramé et al., 2017). Evidence from Hebrew shows morphological processing can occur independently of surface form and meaning (Bick et al., 2008–2011), while Italian and Dutch data similarly support decomposition (Carota et al., 2016; De Grauwe et al., 2014) and the involvement of LIFG for transparent forms. In contrast, the results from Polish and Russian (Bozic et al., 2013; Klimovich-Gray et al., 2017) lean toward whole-word recognition, suggesting cross-linguistic variation. These differences likely stem from language-specific properties – such as morphological transparency and typological structure – as well as task effects, since paradigms like priming and passive listening tap different processes. Altogether, this body of work highlights the complexity of derivational processing and confirms that the question remains unresolved.

For compounding, the few studies conducted and reviewed point towards the involvement of LIFG in compound processing. Further studies are needed to provide us with additional insights about compound processing in the brain.

5 Morphology in the brain: the view from language disorders

Understanding how word knowledge is represented in the brain and how it can be compromised by brain damage is a crucial question in neurolinguistics. While research in this area is still developing, numerous studies have shed light on the connection between specific brain areas and lexical properties, as well as the impact of brain lesions on lexical knowledge. As I showed in Chapter 4, neuroimaging techniques have played a crucial role in identifying brain regions associated with various aspects of word processing. These studies have revealed that different aspects of word knowledge, including morphological properties, are distributed across multiple brain regions.

For example, studies have shown that regions within the left hemisphere, including the LIFG and left STG, are involved in morphological processing. The LIFG is associated with morphological processing related to word production and grammatical processing, while the left STG is involved in auditory word processing and phonological aspects of morphology. In this chapter, I will show how studies with the use of lesion-deficit mapping techniques have provided insights into how damage to specific brain areas can affect different aspects of word knowledge. Lesion studies have demonstrated that damage to the left hemisphere, particularly in regions such as Broca's area and the left posterior STG, can lead to deficits in morphological processing, affecting both production and comprehension. Moreover, research has highlighted the role of white matter connections in facilitating communication between the different brain regions involved in word processing. Damage to these white matter tracts, such as the arcuate fasciculus connecting Broca's area and Wernicke's area, can result in impaired language abilities, including morphological processing.

In sum, investigating how word knowledge is represented in the brain and how it can be compromised by brain damage involves a combination of neuroimaging techniques and lesion-deficit mapping studies. While our understanding of these processes is still evolving, research in this area has provided valuable insights into the neural basis of lexical properties and language disorders. In this chapter, I aim to investigate how our word knowledge about morphologically complex words, as outlined in previous chapters, can be compromised by brain damage. As with previous chapters, I will examine inflection, derivation, and compounding as separate processes. I will present evidence from stroke-induced aphasia (mostly, but not exclusively, focusing on agrammatic, non-fluent aphasia) and from neurodegenerative conditions, such as cortical dementias (Alzheimer's disease, Mild Cognitive Impairment, and Primary Progressive Aphasia). Despite the investigations that will be presented here, one should keep in mind that morphology constitutes an understudied domain in language disorders research.

5.1 Studies on the processing of inflectional morphology[42]

Inflectional morphology is an area of morphology that has been investigated in particular depth when it comes to language disorders, and has been found to be affected in various pathological conditions, such as aphasia, but also various forms of neurodegenerative diseases. Investigating how inflectional morphology is affected by these conditions provides insights into the underlying neural mechanisms involved in language, and it helps us understand the broader cognitive and neural underpinnings of language processing. It can also contribute to developing diagnostic tools and therapeutic interventions (see Chapter 6). For instance, specific patterns of morphological impairment might help in distinguishing between different types of aphasia or stages of neurodegenerative diseases. In the following sections, I present how inflectional morphology is affected in stroke-induced aphasia (§ 5.1.1) and neurodegenerative conditions (§ 5.1.2).

5.1.1 Evidence from stroke-induced aphasia

Aphasia is a complex cluster of conditions that affects different language abilities, in both production and comprehension. There is considerable variation in how it manifests, which is typically linked to the specific brain region that has been damaged. In this section, I will focus on the types

42 In contrast to Chapter 4 and the neuroimaging studies, in the current chapter I will include studies that targeted morphosyntactic processing and studies that were conducted at the sentence level, as in many pathological conditions, they constitute the main source of data for the investigation of inflectional morphology.

of aphasia resulting from focal brain damage, and specifically from stroke. The main distinction is between *non-fluent/agrammatic* aphasia and *fluent* aphasia, while *anomic* aphasia completes the list of the three most common types of aphasia.

Non-fluent, agrammatic aphasia usually results from damage in the LIFG (Broca's region, BA 44-45), the basal ganglia, and the insula. Lesions often extend to surrounding areas, including white matter tracks (e.g. arcuate fasciculus, superior longitudinal fasciculus), thus affecting connectivity between frontal and temporal areas, which impacts sentence processing and repetition (Cappa, 2012). This is characterized by effortful, telegraphic speech with reduced grammatical complexity (Goodglass et al., 1979). People with non-fluent aphasia often struggle with sentence production and word retrieval but have relatively preserved comprehension, especially for simple sentences (Kean, 2013).

While agrammatic aphasia primarily affects language production and morphosyntactic processing, other cognitive domains can also be impacted due to the involvement of frontal brain structures. Two key areas that show deficits in parallel to language are *working memory* and *executive functions* (Caplan, 2012). Deficits in working memory further affect sentence comprehension, especially of complex structures, as well as sentence repetition, particularly of long and complex sentences. Executive function impairment, on the other hand, affects inhibition, and cognitive flexibility, which is manifested in verbal fluency tasks. Other symptoms include *motor planning* and *apraxia*, which affect planning and executing speech, *procedural memory* and *implicit learning*, which are manifested in the inability to learn and apply grammatical rules, and finally, *social cognition* and *pragmatic abilities*, which result in impaired turn-taking in conversation due to slow, effortful speech.

On the other hand, *fluent aphasia* results from damage in posterior areas (Wernicke's region, BA 22) and it is characterized by fluent but incoherent speech, impaired language comprehension, paraphasic errors, and unawareness of language deficits (National Aphasia Association). Individuals often exhibit deficits in attention and cognitive control (Murray, 2012). Finally, *anomic aphasia* results from lesions throughout the left hemisphere, and it is mainly characterized by word finding difficulties, circumlocutions, and preserved comprehension and repetition abilities (National Aphasia Association).

Among the various types of aphasia resulting from stroke, *agrammatic aphasia* most severely affects the use of inflectional morphology. Individuals with agrammatic aphasia tend to either omit inflectional morphemes or replace them with others. *Fluent aphasia* also affects the use of inflectional morphology, but it is thought that this happens to a lesser degree. As mentioned in Chapter 3 (§ 3.1), various factors need to be taken into consideration when exploring inflectional morphology. An important dimension to be considered is *regularity* in the inflectional paradigms, in other words, whether the inflected form is the result of the application of specific rules, such as the addition of *-s* to denote plural (*girl* → *girls*) or whether the form is idiosyncratic (*mouse* → *mice*). Dissociations between regular and irregular forms have been observed in the aphasiology literature. For instance, an individual with agrammatic aphasia, who suffered from lesions in the frontal areas of his brain, as reported by Shapiro and Caramazza (2003), had better performance with regular verbs (*play* → *played*) than irregular ones (*go* → *went*). Nonetheless, this pattern was not observed with nouns (*mouse* → *mice, wolf* → *wolves*), suggesting that the impairment might be more related to the grammatical category than to regularity vs irregularity of the inflectional morphology, without excluding interaction of the two, an issue that I revisit below.

Several studies have targeted the question of the locus of processing regular vs irregular morphology, and although the results are not fully clear, there are indications of a dichotomy between anterior and posterior regions and the processing of regular vs irregular morphology, respectively. This dichotomy is predicted by the declarative/procedural model (Ullman et al., 1997; Ullman, 2001). The model holds that the memorization of idiosyncratic lexical forms (*irregular forms*) depends on the declarative system, while the application of rules for the creation of hierarchical structures (*regular forms*) depends on the procedural memory systems. These two memory systems depend largely on distinct neurobiological substrates. Declarative memory and long-term storage largely depend on the temporal and parietal lobes, while the procedural system is rooted particularly in circuits connecting the basal ganglia with regions of cortex in the frontal lobe.

Several studies found evidence in favor of this pattern. For instance, individuals with non-fluent aphasia were reported to exhibit deficits in producing real and novel regular inflected forms (Ullman et al., 1994, 1995, 1997; Badecker & Caramazza, 1987, 1991; Coslett, 1986; Marin et al., 1976). On the other hand, fluent aphasics show a different pattern than non-fluent aphasics, eliciting worse performance at irregular than regular English past tenses in production (Ullman et al., 1997) and priming tasks (Marslen-Wilson & Tyler, 1997, 1998; Tyler et al., 2002). For further discussions of this perspective, see Walenski (2015).

Another variable that appears to be at play when investigating inflectional morphology is whether *verbal* morphology or *nominal* morphology is involved. In other words, whether speakers inflect a noun (*girl* → *girls*) or a verb (*play* → *played*). Verb processing is, in general, a more demanding operation compared to nominal processing, mostly because verbs carry a lot of grammatical information (de Almeida & Manouilidou, 2015). That is, verbs carry core semantic properties of the events and states that sentences describe, while at the same time they license a great deal of information about the nature of the syntactic arguments that are constitutive of grammatical sentences. A couple of studies shed light on the dissociation between these two grammatical categories when it comes to their inflectional morphology. For instance, Shapiro and Caramazza (2003) as well as Tsapkini et al. (2002) showed that people with aphasia (pwA) with left frontal damage have more difficulties with verbal morphology compared to nominal morphology. On the other hand, Shapiro et al. (2000) presented evidence showing that people with fluent aphasia and posterior lesions, such as left temporal or temporo-parietal lesions, performed better at producing verbs compared to nouns. These two facts together support the idea of the dissociation between verbal vs nominal inflectional morphology following brain damage in distinct brain areas, pointing towards the different neural correlates of verbal vs nominal inflection. According to a commonly held opinion, noun processing is specifically subserved by temporal areas, while the neural underpinnings of verb processing are in the frontal lobe (but see Crepaldi et al., 2011, for a review).

With regard to *nominal* inflections *per se*, the few studies that have dealt with this issue showed that the more problematic domains are the formation of plural forms for nouns and adjectives and the feminine form of adjectives in Italian (Miceli & Caramazza, 1988), as well as case morphology in Basque, i.e. the production of noun phrases with ergative when the absolutive case is required (Laka & Korostola, 2001). A more recent study comparing directly verbal vs nominal inflections in aphasia (Laiacona & Caramazza, 2004) showed that in elicitation tasks where speakers produced verbal and nominal forms that were homophonous, e.g. *suono*$_N$ 'sound' vs *suono*$_V$ 'I play', some individuals had no difficulty producing *suoni* as a noun in the context *un suono, due* … 'one sound, two….', but they could not produce *suoni* as a verb in the context *io suono, tu* …. 'I play, you …'. At the same time, other individuals had exactly the opposite pattern, that is, they had difficulties with the production of nominal inflection.

The recent literature in aphasiology has consistently demonstrated that agrammatic speakers exhibit selective impairments in using *verbal* inflections, particularly in *tense* and *aspect* marking. Across many tensed languages (such as Indo-European ones), time reference is encoded through verb inflection. Morphosyntactic difficulties, such as those observed in aphasia, are therefore likely to negatively affect the ability to process time reference through verbal inflection and to set the temporal framework of discourse, with a significant impact on daily communication.

Cross-linguistic research shows that both tense and aspectual marking are severely and sometimes equally affected in agrammatic production and comprehension (Faroqi-Shah & Dickey, 2009; Fyndanis et al., 2012; Varlokosta et al., 2006). Nonetheless, agreement morphology tends to be relatively preserved in agrammatic aphasia (e.g. Friedmann & Grodzinsky, 1997; Fyndanis et al., 2012; Kok et al., 2007; Nanousi et al., 2006; Varlokosta et al., 2006; Wenzlaff & Clahsen, 2004), although significant variation in individual performance within the category of tense is observed among participants. Some recent cross-linguistic studies have demonstrated that agrammatic individuals struggle with time reference regardless of tense, with more pronounced difficulties when referring to past events compared to the future or present tense (e.g. Bastiaanse, 2008; Bastiaanse et al., 2011; Dragoy & Bastiaanse, 2013; Martínez-Ferreiro & Bastiaanse, 2013; Rofes et al., 2014; Yarbay Duman & Bastiaanse, 2009; Koukoulioti & Bastiaanse, 2020). These difficulties with past reference have been attributed to the complexity of linking to pre-established discourse time points (the PAst DIscourse LInking Hypothesis – PADILIH), a move led by Bastiaanse et al. (2011), which increases the difficulty of grammatical encoding and thus raises the likelihood of errors (Avrutin, 2000), something which goes beyond the use of inflectional morphology as an independent domain of grammar, and it is mostly related to semantic-conceptual factors. However, several cross-linguistic studies have failed to replicate this finding, showing no difference between past and future tenses, which appear to be equally impaired in comparison to present (for English: Faroqi-Shah & Dickey, 2009; Dickey et al., 2008; Faroqi-Shah & Thompson, 2004, 2007; Faroqi-Shah & Friedman, 2015; for German: Burchert et al., 2005; Wenzlaff & Clahsen, 2004, 2005; for Greek: Fyndanis et al., 2012, 2018a; Varlokosta et al., 2006; Nerantzini et al., 2020). Interestingly, a couple of studies (for Russian: Dragoy & Bastiaanse, 2013; for Greek: Fyndanis & Themistocleous, 2019) revealed a possible interaction between time reference, which has been found to be selectively impaired in agrammatic aphasia, and grammatical aspect. For instance, Dragoy and Bastiaanse (2013) compared present imperfective verbs with past imperfective verbs and future perfective verbs with past perfective verbs, finding a significant interaction between time reference and aspect. Reference to the past was less impaired when tested within a perfective aspect context (compared to when tested within an imperfective aspect context), and reference to the non-past was less impaired when tested within an imperfective aspect context (compared to when tested within a perfective aspect context). Findings of this type suggest that the impairment might be outside the domain of inflection and within more semantic-conceptual spheres.

The debate is still ongoing, and it goes beyond the use of inflectional morphology to include time reference in general and its use to build the temporal framework of discourse. Two recent meta-analyses, one by Faroqi-Shah and Friedman (2015) and the other by Cordonier et al. (2024), are not in total agreement. Faroqi-Shah and Friedman (2015) included a total of 106 participants (143 datasets), all of them described as having either Broca's or agrammatic aphasia. They found that tensed verbs were significantly more impaired than neutral (non-finite) verbs, but they did not find consistent differences between past and other tenses in the production of individuals with aphasia. On the other hand, in the meta-analysis of Cordonier et al. (2024), which included data from 232 participants with fluent and non-fluent aphasia, the past tense appears more impaired than present and future. Both meta-analyses underline the role of the interplay of time reference and the cognitive resources it requires, and its realization in inflectional morphology through a specific task. That is, various factors such as task effects, socio-demographic factors, and inter-individual differences among participants need to be better understood in order to form a clear view of the type of deficit that is manifested in the use of inflectional morphology in aphasia. Moreover, the functional, neuroanatomical origin of this impairment is not clear, given that the participants included in the meta-analyses, especially the one conducted by Cordonier et al. (2024), exhibited either fluent or non-fluent aphasia, which usually result from damage to different brain regions.

5.1.2 Evidence from neurodegenerative conditions

Neurodegenerative conditions cover a wide range of diseases that, as the name suggests, are related to brain neurodegeneration. The most common among them is Alzheimer's disease (AD), as it accounts for an estimated 60% to 80% cases of dementia. As such, there is a considerable body of research on language and AD compared to other types of dementia, and this section will therefore mostly (but not exclusively) be dedicated to this condition. Other conditions that will be reviewed are Mild Cognitive Impairment (MCI) and Primary Progressive Aphasia (PPA).

The exact cause of AD remains unknown, but it is believed to result from a combination of genetic, environmental, and lifestyle factors (DeTure & Dickson, 2019). The main pathological changes involve the excessive presence of amyloid plaques and neurofibrillary tangles (Ryan et al., 2015). The accumulation of Aβ plaques disrupts cell-to-cell communication and triggers inflammatory responses that can damage brain cells. Tangles, on the other hand, disrupt neuronal transport and lead to cell death. Combined, the accumulation of amyloid plaques and neurofibrillary tangles leads to the death of neurons and the subsequent atrophy of affected brain regions, particularly the hippocampus and cortex, which are critical for memory and cognitive functions.

AD typically progresses through several stages, with clinical features varying depending on the severity of the disease. The early stage (mild AD) is characterized by memory loss, especially of recent events, by problems finding the right words (anomia), struggles with decision making and problem solving, and subtle personality changes. In the mild stage (moderate AD), memory further declines, as well as language impairment, while activities of daily living (ADLs) are affected. Finally, in the late stage (severe AD), memory loss becomes profound, communication is severely affected, and physical decline is such that it requires full-time care and assistance with all ADLs.

The cognitive profile in AD is marked by progressive and widespread cognitive decline. Memory impairment is the hallmark feature, and often the first noticeable symptom. As the disease progresses, language, visuospatial abilities, executive functions, attention, and social cognition are increasingly affected, leading to a comprehensive and debilitating impact on daily life and functioning. The progression and pattern of cognitive decline can vary among individuals, but the overall trajectory is one of gradual deterioration in cognitive abilities.

Regarding memory loss, the most prominent and earliest observed deficits occur in *episodic memory*, which involves the ability to recall specific events, experiences, or episodes from the past. Episodic memory loss occurs several years before the onset of the disease (Bejanin et al., 2017; Rao et al., 2022 for a review). People with AD (pwAD) often have difficulty forming new memories (anterograde amnesia) and may struggle to recall recent events or conversations. As the disease progresses, *semantic memory* (the memory of meanings, understandings, and other concept-based knowledge) is also affected (Bejanin et al., 2017). This can lead to difficulties in naming objects, recognizing faces, and understanding words. Finally, *working memory*, which is responsible for holding and manipulating information over short periods, is also impaired, making it challenging to follow conversations, plan tasks, or solve problems (Guarino et al., 2019, for a review).

Another affected cognitive domain concerns *visuospatial abilities*, which are demonstrated in difficulty recognizing familiar objects and faces, a condition known as agnosia. PwAD may not recognize familiar people, even close family members (Mandal et al., 2012). Problems are also recorded with spatial orientation and navigation, leading to disorientation in familiar environments (Coughlan et al., 2018). PwAD may get lost in previously well-known places or have trouble finding their way around the home. Finally, *executive function* is another affected domain (Guarino et al., 2019) which includes planning and problem solving, poor judgment, and impaired decision making as well as reduced inhibition when it comes to inappropriate responses or behaviors, leading to impulsiveness or socially inappropriate actions. This, in combination with impaired ability to recognize others' emotions and understand others' perspectives, leads to difficulties in social interactions and thus to social withdrawal.

5.1.2.1 Inflectional morphology in AD

AD is characterized by pronounced language difficulties that already appear at the initial stages and continue to worsen as the disease progresses. Difficulties in retrieving the correct word or name, commonly known as "word-finding difficulty" or "anomia", are among the earliest indicators of AD. PwAD may replace words with similar meaning or sound, or rely on vague terms such as "thing" or "it". Another early symptom is reduced verbal fluency, marked by fewer spontaneous words and slower speech. This deficit is particularly pronounced in tasks requiring the generation of words within a specific category or beginning with a particular letter. As the disease progresses, pwAD may also struggle with comprehending complex sentences or performing tasks that demand the processing of intricate syntactic structures (for a concise description of language problems in AD, see Manouilidou, 2025).

A variety of tasks have been used to explore how *inflectional morphology* is affected in pwAD.[43] The results are often contradictory, as they depend heavily on the *type of task* and its demands with respect to working memory involvement. Another important variable is *the stage of the disease* (mild vs moderate vs severe), and finally whether the target of investigation is *production* or *comprehension*.

Starting with the investigation of the production of inflectional morphology, assessment has been conducted through a variety of structured and

43 Auclair-Ouellet (2015) offers a systematic review of studies that investigate the comprehension of inflectional morphology in AD, and Williams et al. (2021) offers a systematic review of studies that deal with verb processing in AD. Finally, Varlokosta et al. (2023) offers an overview of the methodological techniques used in the investigation of morphosyntax in AD which includes useful information about inflectional morphology.

unstructured tasks, each of which reveals either preserved or impaired abilities. In a picture description task with Hebrew-speaking pwAD, Kavé and Levy (2003a) found that their performance did not differ from their age-matched control groups in the number of inflected words produced and in the proportion of morphosyntactic errors. In contrast, Ahmed et al. (2012) used the same task to examine English participants with mild AD, and found a reduction in the production of inflected words compared to controls.

The same controversial image also emerges when interviews and story narration were used for the investigation of production. For instance, in an interview conducted by Blanken et al. (1987) with German-speaking participants with mild to moderate AD, inflectional errors were rare. In contrast, Altmann et al. (2001), in an interview with English-speaking participants, report errors in both verbal and nominal inflection, in the same vein as Hoffman et al. (2010) with Hungarian pwAD. Similarly, Sajjadi et al. (2012a), by using semi-structured interviews, found that pwAD performed frequent verb agreement errors. When it comes to story narration, Bose et al. (2021), by examining six people with mild AD, all speakers of Bengali, found that they used correct and appropriate inflections for nouns and verbs and a similar proportion of inflected nouns compared to controls.

The distinction between *regular* and *irregular* verbs was investigated in several studies using English and Italian stimuli.[44] For English, Ullman et al. (1997) showed that pwAD with posterior (fluent) aphasia demonstrated better performance on regulars than irregulars. By using a similar methodology to Ullman et al. (1997), that is, a sentence completion task, Colombo et al. (2009) and Walenski et al. (2009) both tested Italian-speaking individuals with AD and reported problems with irregular verbs. Specifically, Colombo et al. (2009) found errors on irregular verbs of specific conjugations, while Walenski et al. (2009) reported impaired performance at the production of past-participle and present tense forms of irregular existing and novel verbs; at the same time, the production of real regular past-participle and present tense forms was intact. Regularizations of novel verbs were similar to those produced by controls. This performance

44 Walenski (2015) offers a good overview of the regular vs irregular production of inflectional morphology in AD and other disorders within the procedural/declarative model (Ullman et al., 1997)

is compatible with damage to temporal lobe cortical regions that results in a declarative (semantic) memory deficit, leading to an impairment of memory-dependent inflected forms, including irregulars, certain regulars, and semi-regulars.

Similar to aphasia, *verbal inflectional* morphology in AD has attracted more attention than its nominal counterpart. One study by Fyndanis et al. (2013) and another by Manouilidou et al. (2020) provided evidence from Greek that shed further light on problems with inflectional morphology, which might reflect deeper conceptual difficulties. Specifically, Fyndanis et al. (2013), using a sentence completion task, tested the realization of tense, aspect, and agreement using different inflections. They found a lower performance for pwAD in all verb features compared to a control group. A difference between the three functional categories was also observed, with the category of aspect being the most impaired and with tense being more impaired than agreement. Manouilidou et al. (2020) also found impairments with grammatical aspect independently of the type of aspect (perfective vs imperfective). A later study (Fyndanis et al., 2018b) comparing Greek to Italian speakers highlighted the role of the language-specific properties on morphosyntactic production. That is, while time reference was more impaired than agreement and mood in Greek, mood was found more impaired than agreement and time reference in Italian.

As with stroke aphasia (see § 5.1.1), the observed problems with the production of inflectional morphology may not be morphological problems *per se*. Instead, it seems that they reflect deeper conceptual/semantic difficulties, which are manifested at the sentence level as impaired production of inflectional morphology. These problems are also linked to the general cognitive difficulties pwAD demonstrate, such as issues with semantic and working memory, and they are deeper connected with the sites of brain atrophy.

Regarding *comprehension*, there seems to be a discrepancy between untimed offline and timed online studies. Studies examining explicit or offline comprehension of inflectional morphology, where the participants are asked to judge presented material, in most cases have revealed impairments in various forms of agreement. While Kavé and Levy (2003b) showed intact ability to detect person and tense agreement violations, deficits were found in several other studies in processing number agreement in both nouns (Grossman et al., 1995) and verbs (Fyndanis et al., 2013). Impairments were also observed in detecting violations of tense and aspect agreement (Fyndanis et al., 2013). In a similar vein, Kempler et al. (1998) and MacDonald et al. (2001) also report problems in detecting violations of agreement and violations related to verb transitivity.

However, these effects observed in offline comprehension do not always appear in online comprehension. For instance, while Kempler et al. (1998) found worse performance on the offline grammaticality judgment task, when they used an online cross-modal naming task they discovered that pwAD showed normal sensitivity to subject-verb agreement errors, indicated by longer reading times for grammatically incorrect sentence continuations. While the offline task performance was correlated to working memory deficits, the online processing was not, which could account for the difference between the two tasks. To explore this further, a similar research team (MacDonald et al., 2001) reanalyzed the same grammatical data alongside a new working memory task thought to be more closely tied to language than traditional tests, and the result was similar to that in Kempler et al. (1998).

The findings from Kempler et al. (1998) and MacDonald et al. (2001) partially align with those of Kavé and Levy (2003b). In their study, Hebrew-speaking participants with AD demonstrated typical online processing patterns, showing a delayed response following subject-verb gender agreement violations. However, unlike previous studies, these participants also performed well in offline tasks involving tense and person agreement.

In sum, inflectional morphology in AD appears impaired in some tasks, reflecting deficits not only in semantics but also in working memory, in line with temporal and parahippocampal atrophy. A key concern is that many studies group together individuals with mild and moderate AD, referring to them collectively as having “mild-to-moderate” AD. This approach obscures stage-specific linguistic profiles and overlooks significant changes that occur as the disease progresses. Additionally, there is a critical lack of research on preclinical stages, such as MCI. Another major limitation is that many studies do not report general cognitive measures or details of the specific assessments participants have undergone, with even fewer examining correlations between language performance and cognitive decline. Finally, despite the existence of studies using languages other than English that were mentioned here, there is a clear dominance of research conducted on English-speaking individuals, limiting cross-linguistic insights (see Manouilidou, 2025).

5.1.2.2 Inflectional morphology in PPA

A set of interesting and informative data originates from a series of recent studies on PPA. PPA is a clinical syndrome caused by forms of neurodegeneration, in which language is the main area of dysfunction for at least the initial stages, while other cognitive functions such as memory, behavior, and visuospatial abilities deteriorate as the disease progresses (Mesulam, 2013). Based on language impairments and neuropathological criteria, three major PPA variants have been reported (Gorno-Tempini et al., 2011): the *semantic variant of PPA* (svPPA), which is linked with deficits in semantic knowledge and object naming, and is also referred to as *semantic dementia*; the *logopenic variant of PPA* (lvPPA), which is characterized by impaired word retrieval and sentence repetition; and the *non-fluent/agrammatic variant of PPA* (nfavPPA), which is associated with grammatical impairments across linguistic domains in both production and comprehension. According to Gorno-Tempini et al. (2011), for nfavPPA and svPPA, frontotemporal lobar degeneration is the underlying pathology, but for lvPPA, AD pathology is the most common underlying cause. However, a later study conducted by Mesulam et al. (2014) showed that AD pathology was detected in many cases of nfavPPA and svPPA, while the link between AD pathology and lvPPA is considerably less consistent than previously thought.

Inflectional morphology was examined in all three variants of PPA (for a review see Auclair-Ouellet, 2015), with the majority of the studies focusing on the nfavPPA.

Inflectional morphology in nfavPPA: Production studies

In most studies, language production was assessed through connected speech,[45] as elicited using story narration, picture descriptions, or

45 Connected speech refers to natural, continuous speech in full sentences or discourse, as opposed to isolated words or syllables.

semi-structured interviews. According to Boschi et al. (2017), semi-structured tasks are better suited for the detection of morphosyntactic features, compared to picture descriptions. As with stroke-induced aphasia and AD, the investigation of *verb* production has a central role when it comes to PPA as well. Studies employing story tasks, such as the Cinderella task, generally reported impairments in verb inflection (Thompson et al., 1997, 2012, 2013a). However, the most striking piece of evidence is the heterogeneity revealed after individual analyses. That is, while some participants exhibit severe impairments, others show no deficits (Thompson et al., 1997, 2012). Moreover, the results of Fraser et al. (2014) brought to light no significant differences between participants and controls in the number of inflected verbs produced.

Studies using picture descriptions or semi-structured interviews similarly found no significant differences between non-fluent participants and controls in the proportion of inflected verbs (Knibb et al., 2009; Wilson et al., 2010) or verb agreement errors (Sajjadi et al., 2012a). Additionally, Sajjadi et al. (2012a) reported that only the "mixed PPA"[46] group – characterized by features of multiple PPA variants – demonstrated significantly more verb inflection errors than controls.

In a comparison between nfavPPA and lvPPA, Thompson et al. (2013a) used the NAVI (Northwestern Assessment of Verb Inflection) and found that nfavPPA participants were more impaired than lvPPA participants in producing tense-marked verbs in phrases. However, lvPPA participants did not perform at ceiling either (see below), but as the study did not include a control comparison, one cannot draw any safe conclusions. Finally, Lukić et al. (2024) in an automated morphosyntactic analysis comparing morphosyntactic markers in connected speech of people with lvPPA and nfavPPA, clearly showed that nfavPPA produced fewer morphosyntactic elements (including verbal-related features, such as verb tenses).

In relation to the distinction between regular vs irregular forms, a case study by Caño et al. (2010) reported that their nfavPPA participant showed greater difficulty producing irregular than regular verbs in writing, which

46 *Mixed PPA* refers to a subtype of PPA that exhibits clinical features of both the nfavPPA and the svPPA variant, without fully meeting criteria for either. It is sometimes referred to as an unclassifiable, overlapping, or *mixed* variant of PPA.

the authors attributed to impaired processing of morphologically complex verb forms. In another study, Wilson et al. (2014) examined the production of past-tense verbs and plural nouns in 48 participants with all three variants of PPA. They predicted that nfavPPA participants would exhibit general morphological deficits. However, their participants only showed impairments for low-frequency irregular words (such as *goose → geese* and *fling → flang*) and especially with pseudowords, while their performance on regular words remained intact.

Finally, there are two studies that focus exclusively on the nominal domain. Stockbridge et al. (2021b) and Stockbridge et al. (2021a), by using a constrained morphosyntactic generation test, showed that people with nfavPPA exhibited greater difficulty with possessive marking (e.g. *Mary's shoe*) compared to plural formation (e.g. *two shoes*). However, their performance was better compared to the other two variants of PPA.

Inflectional morphology in nfavPPA: Comprehension studies

Research on the comprehension of inflected words in nfavPPA remains limited, with only three studies addressing this topic, all conducted by the same research group. Murray et al. (2007) explored how participants acquired a novel or rare verb introduced within a storytelling framework, assessing their understanding of its semantic, grammatical, and thematic properties. In a grammaticality judgment task, the participants frequently rejected correctly inflected forms of the new verb, suggesting difficulties in learning and recognizing its grammatical rules.

Two additional studies examined online processing of inflected words, yielding mixed findings regarding non-fluent participants' sensitivity to grammatical violations. Grossman et al. (2005) and Peelle et al. (2007) used a word-monitoring task in which the participants pressed a button upon hearing a target word in a sentence, with some trials introducing grammatical errors before the target word. Grossman et al. (2005) found that when a grammatical error (e.g. subject-verb or determiner-noun agreement violation) preceded the monitored word, non-fluent participants, like controls, exhibited longer response times, indicating sensitivity to the violation. However, while controls showed a reduced effect when the target word appeared several syllables later, non-fluent participants exhibited an increased delay, interpreted as a sign of slowed syntactic processing.

In contrast, Peelle et al. (2007) found no evidence that non-fluent participants detected grammatical violations, specifically the omission of the *-ed* morpheme in past participles, regardless of when the target word appeared. The authors suggested that these conflicting results might stem from differences in the types of grammatical violations studied, pointing to potential variability in how nfavPPA affects morphosyntactic processing.

Inflectional morphology in lvPPA

While group-level analyses (usually comparing lvPPA to other variants) generally suggest that inflectional morphology remains intact in lvPPA, individual case studies may indicate a more nuanced reality. Some individuals show preserved morphological abilities, whereas others deviate from this pattern. Sentence comprehension deficits in lvPPA are well-documented and typically attributed to phonological loop dysfunction, but not to impaired inflectional morphology processing (Gorno-Tempini et al., 2004, 2008). Despite its significance, research on morphology in lvPPA remains scarce, with only a handful of published studies devoted just to lvPPA. Among these, one focuses on single-case analyses (Zimmerer et al., 2014), another study tracks morphological changes over time (Hilger et al., 2014), while a third provides data on two participants in supplementary materials (Sajjadi et al., 2012a).

Zimmerer et al. (2014) is the only study focusing on comprehension. It presents the case of a man who performed at ceiling in understanding passive sentences but only at chance for active sentences, despite their typical classification as simpler and less susceptible to impairment. Through sentence-picture matching tasks, the researchers found that he was sensitive to the word ‘by’ as an agent marker and to verb morphology in passive sentences (marked with ‘-ed’). He effectively used these cues to process passive sentences correctly, due to his preserved inflectional morphology knowledge. On the other hand, Hilger et al. (2014) revealed a progressive decline in the number of correctly inflected morphemes (verbal and nominal) over a 27-month period for one participant with lvPPA in the cookie theft description. While the frequency of morphosyntactic errors remained stable, grammatical mistakes contributed to lower ratings in the description of the picture.

Most of the studies investigating inflectional morphology in lvPPA, approach it in comparison to other neurodegenerative conditions, such as AD (Cho et al., 2022) or other forms of PPA (e.g. Thompson et al., 2012, 2013a; Sajjadi et al., 2012a; Wilson et al., 2010, 2014; Lukić et al., 2024). When looking at controlled and connected speech data, two studies have examined verb production in structured tasks requiring participants to inflect verbs within phrases. As I showed earlier, Thompson et al. (2013a) found that lvPPA performed better in producing finite verbs (inflected for tense) compared to nfavPPA participants, though both groups performed comparably well with non-finite verbs. However, lvPPA participants did not achieve ceiling performance on finite verbs, with accuracy reaching only 75.3% for present plural verbs. In contrast, Wilson et al. (2014) in an elicited production task targeting inflection, found that lvPPA participants performed significantly worse than controls when inflecting pseudowords and low-frequency irregular verbs, a pattern attributed to phonological and lexical deficits.

Most connected speech studies (Sajjadi et al., 2012a; Thompson et al., 2012, 2013a; Wilson et al., 2010) suggest that verb morphology remains largely intact in lvPPA. A closer examination of individual performances suggests variability that is not always captured in group analyses. In a semi-structured interview analysis carried out by Sajjadi et al. (2012a), only one of the two participants with lvPPA made a small number of subject-verb agreement errors (4/100), and the other made no mistakes at all. In a Cinderella story narrative task, Thompson et al. (2012) found that both nfavPPA and lvPPA groups produced fewer grammatically correct sentences than controls. However, verb inflection impairments were observed only in nfavPPA and not in lvPPA. Similarly, the lvPPA group did not differ from controls with respect to nominal inflection, either. More recent findings suggest that individuals with lvPPA may experience greater verb inflection difficulties than previously thought. Cho et al. (2022) reported that lvPPA participants produced fewer tense-inflected verbs than individuals with amnestic AD. Finally, as I showed earlier, Lukić et al. (2024) showed that lvPPA produced more verb-related features, such as verb tenses, compared to nfavPPA.

Given the above inconsistencies, future studies should aim to clarify individual differences and investigate how morphological impairments in lvPPA evolve over time. Further research is thus needed to refine the linguistic profile in lvPPA, especially for morphological abilities, particularly considering the ongoing debate about lvPPA as a distinct clinical entity.

Inflectional morphology in svPPA

The main features of the *svPPA* or *semantic dementia* include impaired single-word comprehension and word-finding difficulties, while spared grammar is considered a key supporting element for diagnosis. Individuals with svPPA generally do not produce frequent or severe morphological and syntactic errors in spontaneous speech. However, some studies reviewed here indicate difficulties in verb inflection and variations in the production rate of inflected forms.

The contrast between *regular* and *irregular* and the past-tense debate (see § 3.1.2) morphology in English has dominated the morphological investigations in svPPA. Studies investigating *production* in controlled contexts suggest that individuals with svPPA or semantic dementia struggle with inflectional morphology, particularly with irregular, low-frequency verbs, while performing well with regular and frequent verbs. This preservation of regular verbs is seen by some as evidence that morphological knowledge remains intact in these individuals (e.g. Jefferies et al., 2005; Patterson et al., 2006; for German: Billette et al., 2020). However, there is also evidence for impaired inflection in French of *regular* (infinitive form ending in *-er*, e.g. *arriver* 'to arrive') and *pseudo-regular* verbs (infinitive form ending in *-ir*, e.g. *partir* 'to leave'), possibly due to impaired concepts for time reference (Auclair-Ouellet et al., 2016b). Other studies indicate that inflectional difficulties are limited to a subset of individuals only, specifically to those with additional core language impairments as a result of atrophy in neighboring language regions, alongside the central semantic deficit of the disease (e.g. Bright et al., 2008).

Another point to consider is that errors mainly emerge during connected speech and specifically in semi-structured interviews, suggesting that other methods may not be demanding enough to reveal morphological issues (Ash et al., 2009). For instance, studies that used semi-structured interviews revealed the presence of morphological impairments (Meteyard & Patterson, 2009; Meteyard et al., 2014; Sajjadi et al., 2012b). On the other hand, studies that used picture descriptions (Sajjadi et al., 2012b; Wilson et al., 2010) and narrations of the Cinderella story (Fraser et al., 2014; Kavé et al., 2007; Thompson et al., 2012) found no morphological impairments in svPPA/semantic dementia.

Similarly, *comprehension tasks* have shown mixed results, with participants performing better on simple tasks compared to more complex tasks but struggling with irregularity (Wilson et al., 2014). For instance, McCarthy and Warrington (2001) found no effect of morphological complexity on word and pseudoword repetition. However, further research found evidence of impairments, such as difficulties in recognizing and comprehending morphologically complex words (Benedet et al., 2006). Evidence from priming studies is similarly mixed. Tyler et al. (2004) and Bright et al. (2008) reported intact priming effects between uninflected and inflected verbs during LDTs. In contrast, individuals with semantic dementia showed deficits in acquiring the grammatical properties of newly learned verbs (Murray et al., 2007) and struggled to select the correct verb inflection in a forced-choice task (Patterson et al., 2001).

Grammatical agreement processing is another domain that yields conflicting findings. Rochon et al. (2004) found impairments in handling complex number agreement, as seen in judgments of sentences where conceptual and grammatical numbers conflicted (e.g. *The gang* [collective, conceptually plural] *of boys fights* [singular] or *the wheel* [distributive, conceptually plural] *on the toys squeaks* [singular]). However, Grossman et al. (2005) reported that the participants showed normal sensitivity to subject-verb and determiner-noun agreement violations. Similarly, Diesfeldt (2004) found that an individual's difficulty understanding passive sentences stemmed from misinterpreting the preposition *by* rather than a failure to process inflectional morphology.

Studies in languages other than English provide further mixed results. Lambon Ralph et al. (2011) found that Spanish speakers with svPPA struggled to judge noun gender based on word endings, with performance influenced by ending regularity, noun frequency, and severity of semantic impairment. Kavé et al. (2012) reported declining accuracy in adjective-noun gender agreement judgments in Hebrew but stable performance when judging noun-verb gender agreement.

Finally, longitudinal studies show that morphological issues may develop as the syndrome progresses, though the exact cause, whether due to language impairment or central semantic deficits, remains unclear (Rogalski et al., 2011). Neuroanatomical evidence points to atrophy in both semantic and language-processing areas, which is also reported in other studies (Wilson et al., 2014; Bright et al., 2008), but more longitudinal research is needed to clarify these findings and the neurological underpinnings for this performance. Altogether, the findings presented here highlight the variability in morphological processing deficits in svPPA and underscore the need for further research to clarify how different aspects of morphology are affected.

5.1.3 Interim summary

Inflectional morphology has been widely studied in agrammatic aphasia but remains underexplored in neurodegenerative conditions, including AD and PPA. While each disorder presents distinct patterns of morphological impairment the findings vary across studies, highlighting the need for further research.

Specifically, while agrammatic aphasia, AD, and the three PPA variants each present distinct morphological processing deficits, inconsistencies across studies underscore the need for further research. Agrammatic aphasia exhibits well-documented morphological impairments linked to damage in language-processing regions, whereas AD shows more variable deficits, often influenced by task demands. PPA subtypes demonstrate a range of morphological challenges, from severe agrammatism in some nfavPPA cases to more selective impairments in svPPA. Future studies, particularly those incorporating longitudinal designs and cross-linguistic comparisons, are essential for refining our understanding of morphological processing in these conditions.

5.2 Studies on the processing of derivational morphology

Derivational morphology – that is, the production of a new lexical item from another lexical stem, e.g. *girl → girly*, *appear → reappear* – is usually better preserved than inflectional morphology in brain-damaged populations, although considerable variability among conditions and individuals exists. As I showed in Chapter 1 (§ 1.3), several factors contribute to the dissociation between inflection and derivation, such as different degrees of cognitive complexity, functional relevance, as well as neurological factors (see Chapter 4). For instance, the ability to understand and produce inflectional vs derivational forms may rely on different types of processing. With this in mind, it is not surprising that these two domains are differentially affected in various brain-damaged populations, ranging from being more or less intact to being severely impaired. Furthermore, the fact that derivational rules often create new words with distinct meanings belonging to different grammatical classes makes them functionally distinguishable in language use. This emphasis on meaning may help preserve these forms for individuals with language impairments who retain some semantic processing abilities. Finally, the neurological underpinnings of language processing suggest that the brain areas involved in derivational and inflectional morphology may differ in their susceptibility to damage. Areas responsible for higher-level semantic processing may remain relatively intact, allowing for the preservation of derivational forms.

5.2.1 Evidence from stroke-induced aphasia

Miceli and Caramazza (1988) was one of the first studies on derivational morphology in Italian-speaking individuals with agrammatic aphasia. They reported that individuals' ability to use derivational affixes is relatively intact. However, subsequent studies brought to light various interesting facts about the processing of derivational morphology by agrammatic aphasics. For example, Semenza et al. (2002) studied the performance of two Slovenian-speaking individuals, one diagnosed with agrammatic aphasia and the other with transcortical motor aphasia. The study showed that while prefixes (*za-* in *zavezati*, 'tie – tie up') are well-preserved in the grammar of both individuals, with no phonological distortions on them, at the same time, they can be omitted (*svetnik* 'counsellor' instead of *nadsvetnik* 'head counsellor') or substituted (*prihod* 'arrival' instead of *podhod* 'underpass'). This fact suggests that prefixation, as a morphological operation, along with the structure of a prefixed word, are preserved in these two types of aphasia. However, the fact that individuals do not always succeed in producing the correct form of the derived verb suggests certain difficulties with this operation, both for the individual with agrammatic as well as the individual with transcortical aphasia.

An interesting study by Marangolo et al. (2003) reports on two individuals with comparable right hemisphere lesions who showed a selective deficit in the processing of derived words without any other linguistic deficit. This study was the first one to show that derivational morphology can be selectively impaired and that its processing can be mediated by the right hemisphere. Individuals were tested in a picture-naming task where they had to name an action verb or the corresponding derived nouns. They were also asked to produce derived nouns that corresponded to verbs presented to them orally and to produce the verb that corresponded to the nouns they heard. Both individuals were unsuccessful in naming derived nouns from verbs (*liberare* 'to free' → *liberazione* 'freedom'), while they could name verbs from derived nouns (*liberazione* 'freedom' → *liberare* 'to free'). This small-scale study was later partly replicated by Marangolo and Piras (2008) and Marangolo and Piras (2010), who showed that half of the participants tested (five out of the nine in the 2008 study and six out of 12 in the 2010 study) had the same difficulties with deriving nouns from verbs, as in Marangolo et al. (2003). This group of studies has provided some evidence that derivational morphology can be selectively affected and that it can have ties with the right hemisphere and not necessarily with typical language areas. However, a common pitfall of these studies is that the participants were not tested in the naming or the production of non-derived nouns, which calls for caution in the interpretation of the results.

On the other hand, studies support the notion that derivational morphology remains relatively intact in agrammatic individuals. For example, Jefferies et al. (2004) observed that while individuals struggled with verb inflection, they were still able to manipulate derivational affixes, suggesting that the underlying cognitive mechanisms for processing derivational morphology are less affected by agrammatic aphasia. One relevant thing to note is that while all studies assessing inflectional morphology use sentential context, derivational morphology is rarely tested within sentences. This is important, given that sentence processing and integration of inflected forms is more demanding than the out-of-context lexical processing of derived forms.

Finally, a recent study by Ciaccio et al. (2020) compared the performance of three German individuals with agrammatic aphasia in the production of prefixed vs suffixed words. In a reading aloud task, two of the individuals produced an equal number of errors in the production of prefixed and suffixed words, while one of them produced more errors while reading prefixed words. With regard to the types of errors, for two participants these were mostly on the production of individual prefixes rather than suffixes. The authors claim that this dissociation reflects general differences in the processing of suffixes and prefixes. One dimension that the authors consider is that retrieving prefixed words is more costly than retrieving suffixed words, causing larger error rates with prefixed words than with suffixed ones, something which has also been found in the psycholinguistic literature (Colé et al., 1989). However, caution should be exercised when taking into account these findings, as there are very few data from pathological populations on this issue in the literature.

A final dimension to consider is that the ability to utilize derivational morphology may be linked to the semantic processing capabilities of individuals with agrammatic aphasia. As I showed in Chapter 3, derivational morphology is characterized by the fact that particular forms are linked to particular meanings. Apart from being a morphological operation, the creation of a derived form is also a lexical semantic operation. The generation of derived words thus often relies on the semantic connections between words, which can remain accessible even when grammatical processing is impaired, as is the case in stroke-induced agrammatic aphasia. The reliance on semantics more than grammar may facilitate the production of new words.

5.2.2 Evidence from neurodegenerative conditions

In this section, I will show how derivational morphology is affected in three neurodegenerative conditions and, more specifically, in MCI, AD, and PPA. Given the different neurological underpinnings of these conditions compared to aphasia, the neural correlates of morphological operations will be further examined.

5.2.2.1 Derivational morphology in MCI and AD

When it comes to MCI and AD, derivational morphology is certainly an understudied domain. Kavé and Levy (2004) tested 14 pwAD and their sensitivity to the morphological structure of verbs using an LDT. In this task, the participants were asked to determine whether pseudoverbs containing a real verb root were actual words. The researchers hypothesized that, similar to the control group, pwAD would be influenced by the morphological structure of pseudoverbs with a root, resulting in slower responses to these items. The results confirmed this prediction, showing that both pwAD and controls were sensitive to the morphological structure of pseudoverbs containing real roots. Although the AD group made more errors overall, their error patterns were comparable to those of the control group. The authors concluded that these results indicate preserved morphological processing abilities in pwAD, despite their cognitive decline.

Manouilidou et al. (2016) aimed to investigate morphological knowledge in individuals with MCI by assessing their ability to detect violations of word-formation rules in Slovenian, such as **črkilec* 'letter-er', **prebralec* 'reader-through' (for the type of stimuli also see § 3.2.3). They employed two types of tasks: an offline grammaticality judgment task and an online LDT. These tasks were chosen to gather evidence from both non-chronometrized (reflecting more controlled processing) and chronometrized (reflecting more automatic processing) tools. They found that knowledge of morphological rules is preserved in individuals with MCI, as they did not differ from healthy controls in telling apart real words from pseudowords with morphological violations. However, they were considerably slower in doing so, suggesting a deficit linked to the extra-linguistic cognitive system, pointing toward executive dysfunction, a common issue in individuals with MCI, rather than a linguistic problem on its own.

A similar study was conducted by Roumpea et al. (2023) on individuals with AD. They used the same type of materials, that is, Slovenian words and pseudowords violating morphological structure, and showed that AD individuals are successful in recognizing violations of word formations in acceptability tasks, but they differ significantly from controls in online LDTs. This suggests that knowledge of derivational morphology rules is preserved, but also a slower processing speed, which results from executive function impairment, an interpretation along the lines of Manouilidou et al. (2016).

Finally, in a more thorough study, Roumpea (2025) focused on exploring how the complex morphology of deverbal nominals can affect derivation, naming, and lexical processing in AD, given the underlying cognitive impairment of the population. A derivation task, a picture-naming task, an acceptability-judgment task, and an LDT were designed, and 18 healthy controls, four mild-to-moderate-AD, and four undefined-dementia individuals participated in the study. The materials consisted of agent *bralec* 'reader' and process *branje* 'reading' deverbal nominals, and pseudowords that violated categorial **čokoladec*, thematic **ljubilec* and aspectual **prebranje*, **storjenje* restrictions of the formation of deverbal nominals. The results from the derivation task revealed a preserved ability to form deverbal nominals. The picture-naming task revealed difficulties in recalling agent and process deverbal nominals. Impaired lexical processing of deverbal nominals was also observed in the acceptability judgement task and in the LDT. In the latter, categorial constraints were better preserved compared to the aspectual ones. The author concluded that executive dysfunction might have interfered with the ability of the participants to name and process deverbal nominals.

5.2.2.2 Derivational morphology in PPA

As opposed to research on inflectional morphology in PPA, there are much fewer studies on derivational morphology. For this reason, there is only one section devoted to PPA here, where I examine all the variants together. Despite their dearth, recent studies on PPA highlighted interesting findings about various patterns of loss of derivational morphology. Specifically, studies on the svPPA suggest that derivational rules are relatively preserved (Kavé et al., 2012; Stavrakaki et al., 2012, Auclair-Ouellet et al., 2016a). For instance, Auclair-Ouellet et al. (2016a) reported that a female svPPA patient was able to produce derived verbs semantically related to nouns in a transparent way (e.g. *chanter* 'to sing' derived from *chanteur* 'singer'), while when the morphological relationship was opaque e.g. due to root allomorphy (e.g. *correcteur* 'corrector' derived from *corriger* 'to correct'), she produced morphological paraphasias, adding the more frequent productive ending to the noun bases. These findings are in line with previous results supporting a preserved morphological rule system. However, the authors claim that her errors further highlight problems in the final stage of morphologically complex word production, in which the combination of the two morphemes is validated semantically (along the lines of Fruchter & Marantz, 2015, see § 2.1.1). This stage is thought to be necessary to create a well-formed morphological item, and since it involves semantic processing, it is plausible to be affected in svPPA which is characterized by semantic deficits (Auclair-Ouellet et al., 2016a).

Similarly, in a subsequent study, Auclair-Ouellet et al. (2017) also showed that French-speaking svPPA participants had difficulties producing nouns derived from verbs that follow less-frequent patterns of root allomorphy (e.g. *rédacteur* 'writer' from *rédiger* 'to write'), while their performance was less affected when they could rely on basic morphological decomposition/composition abilities (e.g. *chanter* 'to sing' from *chanteur* 'singer'). svPPA participants also had more difficulties matching derived words and pseudowords to a definition, e.g. *que l'on peut laver* 'the one that we can wash' to match with *lavable* 'washable' and do the same with pseudowords as well, e.g. *que l'on peut *miver* to match with **mivable*. Finally, the participants with svPPA could not distinguish pairs of real morphological antonyms *coller* 'stick' and *décoller* 'unstick' and pseudo-morphological non-antonyms, e.g. *fendre* 'split' and *défendre* 'defend'. According to the authors, these findings highlight the role of semantic cognition in validating morpheme combinations and representing derivational morphemes. Difficulties in producing and understanding derived words and derivational morphemes are among the many consequences of the central semantic impairment that defines svPPA.

A recent study by Manouilidou et al. (2021) revealed interesting dissociations between nfavPPA, lvPPA, and stroke-induced agrammatical aphasia in English-speaking populations when confronted with pseudowords violating various rules of word formation. The participants had to make lexical decisions on pseudowords of the type **reheavy*, which violate a syntactic constraint, that is, the grammatical category rule of [*re*- + verb], and of the type **reswim*, which violate a semantic compatibility rule, that is, the rule of [*re*-+ unaccusative verb].[47] The results showed that the

47 For more on this type of stimuli see § 3.2.3

lvPPA group made fewer errors but had slower reaction times compared to the two agrammatic groups, which did not differ from each other in this regard. Accuracy rates suggest that individuals with lvPPA distinguish **reheavy* from **reswim*, reflecting access to different types of information (syntactic vs semantic) and the ability to process them. However, the slow RTs suggest a speed-accuracy trade-off indicative of a strategy which allows this group to use their relatively preserved abilities. In contrast, the two agrammatic groups did not distinguish between **reheavy* and **reswim*. The lack of difference stems from a particularly impaired performance in detecting syntactic violations. Further analyses revealed correlations between their grammatical abilities, as assessed separately, and their performance on the detection of syntactic violations, providing evidence that they rely on their semantic knowledge rather than on anything else to process these pseudowords. Semantically, both **reheavy* and **reswim* fail, and thus the lack of difference between them in the stroke-induced aphasia and the nfavPPA groups.

5.2.3 Interim summary

The first observation is that there are certainly very few studies on derivational morphology in populations with neurodegenerative conditions. Taking the above findings into consideration, it appears that derivational morphology leads its own life when it comes to language disorders. In most cases, it appears better preserved than inflectional morphology. On the other hand, it appears to engage different brain areas, given that derived words exhibit a variety of properties that are not found in inflected forms, such as a distinct semantic component. This component is impaired in both AD and svPPA, and the majority of the studies that investigated derivational morphology in these two conditions relate the observed impairment to deficient semantic cognition. Moreover, the studies by Manouilidou and colleagues highlight the involvement of executive functions in distinguishing between derived pseudowords that violate various types of derivational rules. Both aspects, this one of impaired semantic cognition and the one of impaired executive functions, call upon further investigation, as does the whole area of derivational morphology in neurodegenerative conditions.

5.3 Studies on the processing of compounding

As I showed in Chapter 3, § 3.3, unlike inflection and derivation, compounding forms new words by combining existing lexemes (e.g. *girl* + *friend* → *girlfriend*). This productive morphological process has been widely studied in psycholinguistics, particularly regarding how compounds are stored and accessed in the mental lexicon. Compounds may be represented as whole units (*girlfriend*), decomposed into their constituents (*girl* + *friend*), or both, with factors such as frequency, semantic transparency, relational structure, and headedness influencing processing (see Chapter 3, § 3.3). In this section, I will show what pathological language can teach us about the issues that have occupied the psycholinguistic theory of compound processing, complementing our understanding of compound brain representation. As I did before, I will start with evidence from stroke-induced aphasia, and I will move on to present and discuss the findings with regard to neurodegenerative conditions.

5.3.1 Evidence from stroke-induced aphasia

Most studies on compound processing in stroke-induced aphasia focus on production, with naming studies across languages providing most of the current evidence. Research indicates that individuals with stroke-induced aphasia – including Broca's, Wernicke's, anomic, and transcortical aphasia – recognize compounds' internal structure. This suggests that compounds are not solely stored as whole-word units but are accessed after decomposition to their constituents (Hittmair-Delazer et al., 1994; Semenza et al., 1997; Badecker, 2001; Janssen et al., 2008). Analyses of naming errors show that individuals with various types of aphasia (Broca's, Wernicke's, anomic) often substitute one constituent in production tasks, e.g. *spazzarifiuti*[48] instead of *portarifiuti*[49] 'waste bin' (Semenza et al., 1997), even when dealing with opaque compounds, e.g. **doctorfly* instead of *dragonfly* (Badecker, 2001). Agrammatic individuals also produce misordering errors specific to compounds (e.g. *box post* instead of *post box*), further supporting the notion of structured retrieval processes (Badecker, 2001).

48 The compound is analyzed as *spazza*V 'sweep' + *rifiuti*N 'garbage'.
49 The compound is analyzed as *porta*V 'carry' + *rifiuti*N 'garbage'.

A striking finding is that agrammatic individuals tend to omit the first constituent of Verb-Noun (VN) exocentric compounds (e.g. [[*aspira*]V [*polvere*]N]N/'vacuum cleaner') while preserving Noun-Noun (NN) compounds (e.g. [[*moto*]N [*scafo*]N]N/'speedboat'). This pattern likely arises from difficulties in retrieving verbs in general (Semenza et al., 1997; Mondini et al., 2004; Marelli et al., 2012; Lorenz et al., 2014). Such omissions suggest that compound processing involves decomposition at the structural level. Despite naming impairments, individuals with aphasia maintain structural knowledge of compounds, a phenomenon known as the "compound effect" (Chiarelli et al., 2007; Semenza & Mondini, 2006, 2010). Their errors consistently preserve compound structure, generating either actual compounds or compound-like neologisms (Hittmair-Delazer et al., 1994; Semenza et al., 1997, 2011). Importantly, they do not make similar omissions or substitutions within single words (Badecker, 2001; Kordouli et al., 2018).

Nevertheless, the compound effect is not observed to the same extent in all aphasia conditions, and is less common in individuals with agrammatic aphasia. Unlike other aphasia types (Wernicke's and anomic), agrammatic individuals of Broca's type frequently omit one of the two constituents (e.g. saying *lettere* 'letters' instead of *portalettere* 'carry letters' for 'mailman'). However, like other aphasics, they never respond with a compound when the target is a single word. Moreover, there are often prosodic indications that indicate that agrammatic individuals realize that they are missing one constituent (Badecker, 2001; Kordouli et al., 2018).

Compound retrieval is influenced by both *frequency* and *semantic* transparency. Studies with English- and German-speaking individuals with Broca's and Wernicke's aphasia show that the number of errors decreases when the first constituent is of high frequency (Rochford & Williams, 1965; Ahrens, 1977; Blanken, 2000), though this effect is not consistent across all aphasia types (Hittmair-Delazer et al., 1994). Transparency effects are also complex. Some studies suggest that errors decrease as opacity increases (Dressler & Denes, 1988; Blanken, 2000). For instance, individuals with Broca's and Wernicke's aphasia struggle more with transparent compounds, particularly in retrieving transparent heads (Lorenz et al., 2014). Other studies, however, have shown that substitution errors occur across both transparent and opaque compounds (Blanken, 2000; Badecker, 2001; Ghonchepour & Moghaddam, 2019).

Position effects vary across aphasia subtypes. Agrammatic individuals tend to omit the first constituent, particularly when it is verbal, whereas individuals with Wernicke's and anomic aphasia do not show a consistent pattern (Semenza et al., 1997). In studies of reversible-constituent order compounds (e.g. German *orangensaft* 'orange juice' vs *saftorangen* 'juice oranges'), individuals with Wernicke's aphasia frequently omit the first constituent regardless of its meaning, suggesting positional primacy, given that German is a head-final language (Stark & Stark, 1990). In contrast, one study found that an individual with amnestic aphasia showed no clear positional bias (Delazer & Semenza, 1998).

Italian provides a useful test case for disentangling position from *headedness* effects. Marelli et al. (2014) found that individuals with aphasia struggled more with retrieving modifiers than heads, but only in head-final compounds, reinforcing the role of lexical hierarchy. Moreover, the error analysis of this study (Marelli et al., 2014) showed that modifiers were most often substituted with other words, suggesting that the head constituent is more important during composition. The authors' interpretation is that, given that head constituents specify the most important semantic information of the whole compound, they are more salient from a cognitive point of view and are easier to retrieve than modifier constituents.

Finally, based on the above findings, Marelli et al. (2014) assume that both the *conceptual-semantic* and *lemma* levels (in terms of Levelt et al., 1999) account for headedness effect, given that the head determines not only semantic but also grammatical information of compounds. More specifically, *lemma level* would contain grammatical information (grammatical category and gender) as well as the specification of head and modifier positions, while *conceptual-semantic levels* would be responsible for the actual roles of head-modifier, that is, the conceptual/relational combination between constituents (see Chapter 3, § 3.3.3).

5.3.2 Evidence from neurodegenerative conditions

In § 5.3.1, I showed that neurolinguistic research has explored how brain damage in aphasic populations affects compound processing, revealing error patterns across different aphasic populations. In this section, I will examine compound processing in AD and in PPA, seeking evidence from neurodegenerative conditions.

5.3.2.1 Evidence from AD

The investigation of compound word processing in pwAD is very limited. The work of Chiarelli and colleagues (2005, 2006, 2007) with Italian-speaking participants addressed the question of whether pwAD can name compound words. Meanwhile, Kordouli (2022) studied Greek-speaking pwAD and examined compound production in two offline production experiments and compound processing in two online LDTs using existing and pseudo-compounds.

Chiarelli et al. (2007) examined AD individuals' performance in a picture-naming task. The findings showed that individuals tended to substitute compounds with other compounds in their error responses in 53% of cases. Moreover, in their erroneous responses, they did not preserve the structure of the target compound in terms of the grammatical categories involved. Crucially, they used the most productive structure (i.e., VN compounds in Italian) when they failed to produce the correct compound form (Chiarelli et al., 2007). Furthermore, pwAD seemed more impaired in nouns than verbs, as they made more errors in nominal constituents during compound naming. Chiarelli et al. (2005, 2007) argue that naming difficulties cannot be due solely to problems in retrieving the phonological form/lexeme of compounds in AD. According to the authors, these errors indicate difficulties with the morphological structure of compounds in AD.

Kordouli (2022), using a naming and a production by definition task,[50] reports that compounding poses great production difficulties for pwAD compared to the production of simple words, suggesting that the knowledge about the compositional nature of a compound, structural and semantic, is compromised in AD. This finding agrees with Chiarelli et al. (2007), and it extends to other types of dementia (see the following section

50 In this task, the participants are provided with the constituents, and they are asked to produce the compound. For instance, they were asked *what do you call the house of a doll?* The expected answer was *dollhouse.* The tasks focuses on the combinatorial/structural abilities of the individuals and not on lexical retrieval.

on PPA). An important finding that Kordouli (2022) revealed through a simple LDT and an LDT with priming is that while in other types of dementia individuals were not able to detect violations of the compound structure (structural and morpho-semantic violations), pwAD did not have any difficulties in doing so. For example, Kordouli (2022) created violations of the type **trapuloxar'ti* instead of *trapu'loxarto* 'single card from a deck' in which she manipulated the appropriate structural scheme.[51] She also used morpho-semantic violations, which were created by changing the order of constituents (e.g. **vi'xokseros* 'cough dry' instead of the correct *kse'rovixas* 'dry cough'). PwAD were successful in rejecting these types of pseudo-compounds as existing compounds of Greek. This performance indicates that the ability to detect compound structure violations is relatively preserved in AD (agreeing with studies on inflectional morphology showing preserved morphosyntactic abilities, see § 5.1.2.1).

5.3.2.2 Evidence from PPA

Kordouli and colleagues (2017, 2018, 2022) have extensively examined compound word processing in individuals with all three variants of PPA (lvPPA, svPPA, nfavPPA), comparing them to individuals with AD and those with the behavioral variant frontotemporal dementia. Their findings indicate that morphological and semantic knowledge are compromised in PPA, regardless of whether the primary deficit is semantic (svPPA), phonological (lvPPA), or grammatical (nfavPPA).

In a study using Greek stimuli, Kordouli (2022) used two offline production tasks (picture naming and definition-based production) and two online LDTs to assess both explicit and implicit knowledge of compounds. The results highlight key deficits in PPA populations. First, individuals with PPA exhibited greater difficulty producing compounds than simple words, suggesting impaired structural and semantic knowledge of compositional morphology. Second, unlike pwAD, individuals with svPPA, nfavPPA,

51 The first constituent of a Greek compound is an (uninflected) stem (e.g. *trapul*-stem/'card deck' vs *'trapula'* word/'card deck + inflection), while the second is either a stem as is the case here (e.g. *xart*-/'paper') or a word. Compounds whose second constituent is a stem are stressed on the antepenultimate syllable and may bear a different inflectional ending from that of the second constituent, when taken in isolation (-*xarto* in compounding vs *xarti* in isolation 'paper'), as it is the case with *trapu'loxarto*.

and lvPPA failed to detect structural and morpho-semantic violations in compounds, indicating a compromised understanding of morphological rules. Third, the relational structure between constituents influenced performance, with dependent compounds (*snowball* – 'a type of ball') posing more difficulty than coordinative compounds[52] (*café-restaurant* – 'café & restaurant'), particularly in svPPA and lvPPA. While expected in svPPA due to its hallmark semantic deficits, these findings also suggest that aspects of semantic processing are also impaired in lvPPA. Finally, even the non-semantic variants (nfavPPA and lvPPA) showed vulnerability in the semantic aspects of word knowledge.

The studies outlined above, even though they constitute the only published research on compounding in PPA, contribute to the list of data on complex word processing, demonstrating how this area is affected by various pathological conditions. Once again, factors such as frequency and transparency (either morphological or semantic) seem to play an important role, highlighting the involvement of multiple elements in the processing of complex words. Nevertheless, the rules of word structure are perceived by speakers and affected by different pathological conditions in different ways, emphasizing not only the cognitive part of morphological processing but also its cerebral substrate.

5.3.3 Interim summary

The aim of this chapter was to provide an overview of how morphological operations such as inflection, derivation, and compounding can be impaired in language disorders. The studies discussed here do point towards the theoretical distinction between the three operations, as they are differentially affected by each condition and each syndrome discussed. Inflection, being at the interface of morphology, syntax, and phonology, is primarily (but not exclusively) affected in syndromes that present grammatical deficits. Derivation and compounding, on the other hand, are better preserved in general, and mostly impaired in conditions that affect lexical knowledge. Furthermore, the research presented here highlights the role of specific language systems as well as the role of extra-linguistic factors in the manifestation of deficits, calling for a need for cross-linguistic investigations

52 See Chapter 3, § 3.3, footnote 30

and giving morphology a central role in describing language deficits and by extension in therapeutic intervention approaches, something that I will discuss in Chapter 6.

6 Clinical implications and general conclusions

The current monograph aimed to present key findings from morphological investigations spanning three distinct domains: psycholinguistic behavioral studies, neuroimaging studies, and evidence from language disorders studies. In this final chapter, I will reflect on the importance of morphology in healthcare practice, and I will discuss the clinical implications of the presented research before making some final remarks.

In Chapter 5, I presented several studies dealing with morphology, which have revealed prominent impairments, such as inflectional morphology in agrammatic aphasia. However, even though this finding is very well documented and one of the most robust ones since the 1980s, the assessment of morphology as a separate domain lags seriously behind. It is not entirely clear why this is the case, but if one would like to speculate, then the fact that all current tools and methods are based on original tests created for English, a language with poor morphology, becomes relevant. At the same time, research has shown that some morphological abilities remain relatively intact, such as derivational morphology in agrammatic aphasia. This is another important piece of evidence, i.e., intact abilities, which is left out of therapeutic protocols. Moreover, a variety of studies have pointed out that results often depend on the individual, but we are still very far away from employing individualized interventions. Finally, in several cases, such as in PPA, the domain of morphology was differentially affected by the specific variant (see § 5.2.1.3), suggesting that morphology could contribute decisively to differential diagnosis along with other domains of linguistic assessment.

In what follows, I will present the few existing assessment tools and the very few treatment approaches targeting morphology in neurologically impaired populations. The remainder of the chapter, and based on the above pillars, will highlight the need for more attention to morphology when assessing neurological adult populations and the need to include morphology in therapeutic approaches. I hope that this chapter will trigger the interest of young researchers to direct their attention to morphology when investigating language in neurologically impaired populations, and the interest of clinicians when they are called to assist impaired individuals to overcome their language difficulties.

6.1 Morphology in the language assessment of neurological populations

Not many assessment tools exist that target morphology, and the ones that do so aim almost exclusively at inflectional morphology in aphasia. Derivational morphology is used to a lesser extent as a domain of assessment, while compounding is absent from the existing assessment tools and methods.

The Bilingual Aphasia Test (BAT) (Paradis, 1987), a test created for English-French bilinguals and translated and adapted for 76 languages, is one of the few tools that contains two subtests for derivational morphology. Specifically, the test comprises 10 examples relevant to *derivation* in which participants are instructed to create adjectives from nouns (e.g. *power* → *powerful*; *noise* → *noisy*) and 10 examples for *morphological opposites* in which participants are asked to create a word that means the opposite of the word given to them (e.g. *trust* → *distrust*; *believable* → *unbelievable*). Apart from BAT, the widely used Comprehension Aphasia Test (known as CAT) (Howard et al., 2004), created for English and translated into nine languages, has a section on the repetition of complex words which includes three derived words (*unthinkable*, *defrosted*, *conforming*) and a section on reading complex words which also includes three derived words (*informative*, *recooked*, *presented*). Beyond these two tools, there is nothing else for the assessment of derivational morphology. Worse than that, compounding is not part of any assessment tool whatsoever.

The picture is different when it comes to the assessment of inflection. The Northwestern Assessment of Verb Inflection (NAVI) was designed as a clinical and research tool to systematically examine the presence and nature of verb inflection difficulties in individuals with aphasia and related neurogenic language disorders (see Lee & Thompson, 2017). The NAVI was created based on English, and has been translated into three other languages (Italian, German, and Chinese). It consists of 10 verbs, and it is used to assess one's ability to produce finite and non-finite verb inflection forms in English, using a sentence completion task. Specifically, the verbs are tested in five different verb inflection forms: two non-finite forms (infinitive and present progressive) and three finite inflection forms (third person present singular, present plural, and past tense). Both regular (e.g. *poured*) and irregular (e.g. *wrote*) verbs are tested, allowing a comparison of the production of their past-tense forms. Inclusion of both the third person present singular and plural forms allows assessment of the ability to produce inflectional marking for number agreement (e.g. *the man eats* vs *the men eat*). The target verb inflection form is elicited in sentence frames such as *Now the man is* _____ *the hamburger*. The NAVI can be used in both research and clinical settings to test for the presence of verb inflection difficulties and the nature of such difficulties in adults with language disorders.

Finally, the Verb and Sentence Test (VAST), which is an adaptation of the Dutch test battery *Werkwooden- en Zinnentest WEZT* (Bastiaanse et al., 1997), also targets inflection. Both the Dutch and English versions are linguistically motivated, and they can be used with people with different types of aphasia. The VAST contains a subtest in which participants have to fill in sentences either with finite verbs (n=10) or with infinitives (n=10). The Norwegian version of VAST also contains a section assessing past tense inflection (Lind et al., 2007).[53] As of now, and except for Norwegian, there is no publicly documented evidence that the VAST has been officially translated or adapted into other languages.

Apart from the above, there is no specialized test for the assessment of morphology, despite the existence of various assessment tools for aphasia, which require the production and comprehension of sentences where inflectional morphology plays an important role.

6.2 Morphology in therapeutic approaches to neurological populations

The idea of training linguistic structures in neurological populations is not new. However, the domain of morphology was seldom the primary target. Whenever there were attempts to use morphological cues in language treatment, this was almost exclusively done through inflectional morphology in aphasia in various languages, to improve verb production and comprehension.

53 Thanks to Monica Norvik for bringing this to my attention.

For instance, one of the first attempts was the Verb Production at the Word and Sentence Level (VWS) task devised for Dutch by Bastiaanse and colleagues (1997), which was later translated into German (Bastiaanse et al., 2006) and Italian (de Aguilar et al., 2015). In the VWS, the participants have to retrieve the verb lemma, build a sentence frame around the verb, use verb inflection, and place it in various positions in the sentence depending on the language. Although not morphology-oriented, this type of task includes some morphological training exclusively in the domain of verb inflection. In a similar vein, the Treatment of Underlying Forms (widely known as TUF), put forward by Thompson and colleagues (see Thompson & Shapiro, 2005), focuses on the treatment of three structures, i.e., (1) passive sentences, (2) object cleft sentences, and (3) *wh*-questions. Although morphology is not the main target of treatment, morphological cues are given to the participants to generate the target sentences.[54]

A recent meta-analysis by de Aguiar et al. (2016) dedicated to single-case studies of verb treatment brought to light interesting outcomes with respect to the use of morphology when treating verb retrieval. The authors aimed at distinguishing predictors of improvement for different outcomes, e.g. production of treated vs untreated verbs. They found that verb inflection treatments are effective in generalizing tense production to untreated verbs at the sentence level. However, they also showed that the role of morphology was crucial in the sense that patients whose treatment protocol included morphological cues (consisting in all cases of therapy for tense production) were more likely to show improvement for untreated verbs. However, they also noticed that there is an interaction between the presence of morphological cues and general grammatical impairment. That is, when they compared improvement in people with grammatical impairment, the individuals who did not receive morphological cues in their treatment were less likely to improve. The authors pointed out that a treatment is more likely to be successful when it addresses abstract properties or rules (e.g. *argument structure* as in Thompson et al., 2013b or *inflectional paradigm* as in Links et al., 2010; de Aguiar et al., 2015) that apply to more than one word or sentence. Training

54 In contrast to the above two tests, the Verb Network Strengthening Treatment (VNeST) (Edmonds et al., 2009), which targets the lexical retrieval of content words in sentences, including verbs, does not target verb inflection and it classifies inflectional morphology errors as acceptable, given that they are not targeted in the treatment.

in abstract properties, especially morphological training, may support verb retrieval by reducing the cognitive load of encoding grammatical information, thereby freeing up mental resources for retrieving verbs.

More recently, two studies by Roumpea and colleagues applied neuromodulation techniques for the improvement of derivational morphology in pwAD (see chapter 5, § 5.2.2.1 for detailed descriptions of the behavioral part of the studies). Roumpea et al. (2023) presented a case study of a mild AD participant who received high-frequency (10 Hz) repetitive Transcranial Magnetic Stimulation (rTMS) over the Dorsolateral Prefrontal Cortex (DLPFC) for 15 sessions, taking place daily for three weeks. Post-stimulation evaluation indicated increased accuracy and faster RTs, which lasted up to two months post-intervention.

Finally, Roumpea (2025, forthcoming), in a more thorough study and by using the same protocol, explored improvements in naming, acceptability judgements, and lexical decisions in mild and moderate AD as assessed through a picture-naming task, an acceptability-judgment task, and an LDT targeting deverbal nouns in Slovenian (see § 5.2.2.1). The materials consisted of agent *bralec* 'reader' and process *branje* 'reading' deverbal nominals, non-words **fekarna* and pseudowords that violated categorial **čokoladec*, thematic **ljubilec* and aspectual **prebranje*, **storjenje* restrictions of the formation of deverbal nominals (see § 5.2.2.1). Treatment effects were observed only in the one participant with mild AD, while the participants with moderate AD did not show any improvement. Specifically, accuracy was improved in naming agent and process nouns, suggesting an overall improvement in naming derived words. Similarly, overall accuracy was improved in the LDT, an effect which was mostly triggered by improvement in the accuracy of complex pseudowords. Equally, RTs were improved specifically when it comes to non-word and pseudoword processing. To the best of my knowledge, these are the only two studies dealing with the use of neuromodulation in pathological populations that resulted in the improvement of morphology. They clearly suggest that improvement in the morphological domain is possible in a neurodegenerative condition if we target intervention at an early stage, highlighting the use of high-frequency stimulation of the DLPFC as a potential therapeutic tool to improve morphological processing in mild AD.

6.3 Morphology: the obvious gaps and the way forward

Considering all the above, morphology is clearly missing from standardized tools and intervention protocols as an independent domain. Chapter 5 presented all sorts of impairments related to morphology that go beyond verb inflection, and which are manifested in a variety of neurological populations. For instance, the impairment of derivational morphology and compounding in AD and PPA has important implications for both language assessment and intervention. Standardized language tests may overlook subtle deficits in morphological processing, potentially leading to underdiagnosis or misdiagnosis. To address this, clinicians should consider incorporating tasks that specifically assess derivational morphology and compounding when evaluating language abilities in individuals with AD and PPA. Overall, derivational morphology and compounding represent a critical component of language that is compromised in these conditions. Recognizing and understanding these deficits can enhance the accuracy of clinical assessments and support the development of targeted interventions to help preserve language function.

A related point to consider is that morphological impairments are not an all-or-none process, especially given that morphology spans from inflection to derivation and compounding. Thus, while some morphological domains might be impaired, some others are not. And it is precisely this preservation of some morphological abilities across different populations that may have important clinical implications. For example, derivational morphology tends to remain relatively intact in individuals with agrammatic aphasia (see § 5.2.1), as is the case with inflectional morphology in individuals with svPPA and lvPPA (see § 5.1.2.3). Incorporating derivational forms into the speech therapy of people with agrammatic aphasia could help improve communication by offering them alternative ways to express themselves despite grammatical impairments. Similarly, encouraging people with svPPA and lvPPA to use inflected forms could boost their linguistic confidence and lead to better overall performance. Therefore, understanding how certain domains are preserved in certain conditions not only deepens our insight into language processing, but also guides more effective therapeutic strategies for those affected.

Another important aspect is the use of morphological operations for differential diagnosis. We saw that morphology is not affected in the same way in all neurologically impaired populations. This is particularly relevant when it comes to conditions that are closely related to each other, such as the three PPA variants. In Chapter 5 (§ 5.2.2.3), we saw that people diagnosed with svPPA demonstrate impaired performance when it comes to derivational morphology, while those diagnosed with the other two variants of PPA (lvPPA and nfavPPA) do not. Similarly, in § 5.1.2.3, we saw differences between the three variants with respect to inflectional morphology. Thus, morphological assessment, whether it is performed through automatic morphological analysis (Lukić et al., 2024) or through targeted tasks (Manouilidou et al., 2021), can efficiently differentiate PPA variants from each other, thus contributing to a key challenge in PPA diagnosis. Morphosyntactic assessment and analysis appear to be better predictors than standard assessment for the diagnosis of PPA variants.

Finally, a further point worth mentioning is the need for individualized approaches to treatment and rehabilitation. Section 5.1.2.3 highlighted instances of variability in the degree of morphological impairment and the use of inflectional morphology in individuals diagnosed as belonging to the same PPA variant. By assessing morphology properly, clinicians could target the production of specific morphemes with which the individual has difficulty. That is, therapy could focus, for example, on verbs, but also on other impaired morphemes, such as possessives (e.g. Stockbridge et al., 2021a; 2021b), which might not be problematic for everyone. The findings of Chapter 5 provide a firm foundation for the clinical utility of morphological assessment in language production and comprehension in neurologically impaired populations.

Morphological awareness has long been a decisive factor in improving reading skills in children with dyslexia (see Kaldes et al., 2024 for a recent meta-analysis). Morphological intervention studies have aimed to improve children's reading outcomes, and the use of orthography and spelling within the context of teaching morphology has had important implications. Morphological instruction plays a significant role in supporting struggling readers, especially those in upper elementary through secondary grades, as research shows that explicit and systematic teaching of morphological concepts can enhance reading skills (Washburn Mulcahy, 2018). It was also found that morphological knowledge may play a protective role in language retention, as some researchers have suggested that the preserved morphological ability of participants with letter position dyslexia[55] modulated dyslexic errors and protected the letter position dyslexics from making errors (Friedmann et al., 2015).

Based on these robust findings from domains such as developmental dyslexia, one wonders how morphology has gone so unnoticed, understudied, and underused in the diagnosis and treatment of adult neurological populations. It is not far-fetched to believe that an individual with a stronger understanding of morphology may retain language abilities longer than others who do not understand morphology. It is thus the responsibility of researchers to communicate their findings to the clinical community, and of clinicians to seize the opportunity to incorporate them into their daily practice. Morphology can make a difference.

6.4 General conclusions

This monograph set out to examine morphology through morphological processing and impairment in language comprehension and production. It explored morphology in three distinct domains, i.e., inflection, derivation, and compounding, through a variety of fields, methodologies, tasks, and populations, with the crosstalk of all these domains being challenging at times. Nonetheless, through an analysis of behavioral, neurocognitive, and clinical evidence, it has highlighted the significance of morphology in our processing system and, by extension, to linguistic theory and hopefully, one day, clinical practice. The findings presented here underscore the importance of integrating morphological awareness into models of language processing, as well as into diagnostic and therapeutic frameworks for language disorders.

With regard to the specific goals set out at the introduction, the findings and discussions presented in the previous chapters support the choice of examining inflection, derivation, and compounding as separate domains. Even though for some researchers the distinction between the three is at times rather vague, the findings presented here suggest that it is still an

55 Letter Position Dyslexia is a specific type of reading disorder in which individuals misidentify words because they transpose (swap) the positions of letters within words, especially middle letters, while keeping the first and last letters intact. This results in reading real words as other real words (called *migration errors*).

important one, being supported by different brain responses, and especially one that can lead to differential diagnosis of neurologically impaired populations. It has also become clear how different methodologies and tasks bring to light distinct pieces of knowledge with regard to the puzzle of understanding morphological processing. There is no good or bad methodology, and there is no good or bad task. Each of them contributes a piece to our understanding.

When it comes to more specific questions, such as the big one – if morphology exists and if it is processed and how – in reviewing the literature on the role of morphological structure in lexical access, we have seen how complex morphology can play a crucial role in lexical access and lexical representation. It has also become clear that neither of the extreme positions, strict decomposition or whole-word access, can account for the experimental facts. Instead, a variety of factors interact to determine whether words can be accessed as wholes or through decomposition. More specifically, morphological regularity, frequency, and transparency are interrelated concepts that have played a major role in modelling the role of morphology in the lexicon and in the brain.

As always, while the studies reviewed here may provide compelling evidence, further research is needed to clarify the mechanisms underlying morphological deficits across different populations and languages, as well as the neural underpinnings of morphological knowledge. Future investigations should explore how morphological training can be systematically implemented in clinical and educational settings, and how individual differences in processing shape outcomes.

In sum, understanding morphology is not merely a theoretical pursuit – it holds practical value for improving communication, diagnosis, and intervention in both typical and impaired language development.

Abstract

The present monograph aims to provide a platform for discussing morphological processing across its three major subfields: inflection, derivation, and compounding. The work evaluates the contributions of diverse experimental methodologies, ranging from behavioral chronometric paradigms, such as reaction time tasks, to neuroimaging techniques that capture real-time brain activity (e.g. EEG, MEG) or hemodynamic changes (e.g. fMRI), highlighting the complementary insights each brings to the study of morphology. Of particular importance is research on clinical populations, including individuals with brain damage or neurodegenerative conditions, who are often neglected when studying morphological processing. By integrating findings from reaction-time paradigms, real-time brain imaging, and lesion studies, the monograph aims to clarify how morphological processes are represented in the mind and brain, and how they are affected by brain damage. Ultimately, it seeks to connect experimental evidence with linguistic theory and underscore the clinical relevance of morphology in diagnosing and treating language disorders. As such, it constitutes an interdisciplinary work of reference for those interested in morphology and issues about its processing and representation.

Povzetek

Monografija predstavlja podlago za preučevanje procesiranja morfologije na treh glavnih podpodročjih: pregibanju, izpeljavi in sestavljanju. Delo ovrednoti doprinos različnih eksperimentalnih metodologij, od vedenjskih kronometričnih paradigem, kot so naloge presojanja besed, do slikanja možganov v realnem času, ki zajema aktivnost možganov (npr. EEG, MEG) ali hemodinamske spremembe (npr. fMRI), pri čemer so poudarjeni dopolnilni vpogledi, ki jih vsaka od metodologij prinaša v preučevanje morfologije. Posebej pomembne so raziskave na različnih kliničnih skupinah, vključno z osebami z možgansko poškodbo ali nevrodegenerativnimi stanji, ki so pri raziskavah o procesiranju morfologije pogosto zanemarjene. Prek povezovanja ugotovitev raziskav, opravljenih z merjenjem reakcijskega časa, s slikanjem možganov, in raziskav možganskih poškodb monografija pojasnjuje, kako so morfološki procesi predstavljeni v umu in možganih in kako nanje vpliva možganska poškodba. Končni cilj dela je povezati eksperimentalne dokaze z jezikoslovno teorijo in poudariti klinično pomembnost morfologije pri diagnosticiranju in zdravljenju jezikovnih motenj. S tem predstavlja monografija interdisciplinarno referenčno delo za vse, ki jih zanima morfologija in vprašanja o njenem procesiranju ter predstavitvi v možganih.

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