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# Mental Lexicon Architecture and Morphological Processing of French Verbs

Gustavo Lopez Estivalet

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# **Mental Lexicon Architecture and Morphological Processing of French Verbs**

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*To my grandmothers.*



# Résumé

## **Architecture du Lexique Mental et Traitement Morphologique des Verbes Français**

*Introduction :* Comment les mots sont-ils reconnus? Comment accédons-nous à la signification des mots? Depuis un demi-siècle, de nombreuses études en psycho-, neuro- et linguistique sur l'accès lexical et la reconnaissance des mots se sont intéressées à ces questions. Le traitement morphologique semble être un niveau de traitement essentiel pour l'extraction des informations présentes dans les différentes parties des mots pendant leur reconnaissance. Un des grands débats sur le fonctionnement du langage concerne le stockage des mots dans le lexique mental et les processus pour leur reconnaissance. Par extension, ce débat pose des questions sur la nature des représentations dans le système cognitif. D'un côté, les modèles de « pleine-entrée » proposent un stockage du mot entier dans la mémoire et un traitement morphologique post-lexical basé sur des paradigmes et des associations entre les mots. D'un autre côté, les modèles décompositionnels proposent une décomposition pré-lexicale complète et une activation des représentations morphémiques basées sur des règles phonologiques, morphologiques et syntaxiques. Entre les deux, les modèles à double-mécanisme considèrent deux voies pour la reconnaissance des mots, une route associative avec l'accès direct aux mots entiers et une route combinatoire s'appuyant sur des règles. Ces modèles peuvent aussi être différenciés entre modèles de recherche lexicale et modèles d'activation interactive. Dans le premier, il y a une recherche en sériel du mot ou morphème dans le lexique mental en fonction des fréquences du mot et morphémiques. Dans le deuxième il y a une interaction entre les différents niveaux d'activation : les traits phonologiques et orthographiques à un niveau, le graphème et phonème à un autre niveau, et les mots à un autre niveau ; ces activations se font dans les interactions entre phonologie, orthographe, et sémantique dans des unités cachées.

*Objectifs :* Le principal objectif de cette thèse a été d'étudier le rôle du traitement morphologique dans la reconnaissance des mots. Plus spécifiquement, le but était de rechercher les processus morphologiques mis en place pour le traitement des verbes français fléchis lors de la reconnaissance des mots en modalité visuelle. Les questions qui ont guidé ce travail sont : 1) Comment les mots sont-ils stockés dans le lexique mental ? A partir de représentations des mots entiers ou de représentations morphologiques ? 2) La reconnaissance visuelle des verbes français s'explique-t-elle par des modèles à mécanisme simple ou double ? 3) Le traitement morphologique s'effectue-t-il avant ou après l'accès lexical ? L'hypothèse

nulle est que les mots sont stockés comme des unités entières dans le lexique mental et qu'après l'accès lexical ils peuvent être traités morphologiquement, en fonction des paradigmes flexionnels et des connections entre mots similaires. L'hypothèse alternative est que les mots sont le résultat de combinaisons des unités morphologiques atomiques stockées dans le lexique mental et la reconnaissance des mots est médiée par la décomposition morphologique pré-lexicale.

*Méthode* : Ces questions ont été examinées à travers d'analyses linguistiques et à travers la réalisation de cinq études expérimentales. Ces études se sont appuyées sur des tâches de décision lexicale, d'amorçage intermodal, d'amorçage masqué, de locuteurs bilingues, et d'électroencéphalographie. L'étude 1 a cherché dans une expérience de décision lexicale visuelle l'organisation du lexique mental en fonction des fréquences de surface et cumulée dans des verbes français : réguliers, morpho-phonologiques et irréguliers. L'étude 2 a exploré les processus de formation du radical verbal à partir de la combinaison des morphèmes et des règles allomorphiques des verbes français des 1er et 3ème groupes, avec deux expériences d'amorçage : une à l'amorçage intermodal avec amorce auditive et cible visuelle, et l'autre à l'amorçage masqué visuel de 52ms. L'étude 3 a exploré le rôle des opérations morphologiques des suffixes flexionnels de temps et d'accord dans les verbes français à travers de deux expériences de décision lexicale. Une des expériences portait sur le nombre d'opérations morphologiques, l'autre sur le traitement des traits morpho-syntaxiques spécifiques à l'accès lexical. L'étude 4 a testé le traitement morphologique verbal chez les locuteurs du français comme L2, ayant le Portugais Brésilien comme L1. Cette étude a été effectuée sur les bilingues avec deux niveaux de français comme L2, débutant et avancé ; il a été appliqué trois expériences aussi réalisées auparavant avec des locuteurs natifs, pseudoverbes français, effets de fréquence, et effets d'amorçage. Enfin, l'étude 5 a testé les violations morphologiques verbales dans cinq structures morphologiques de (pseudo)verbes français : vrais mots, non mots, juste radicaux, juste suffixes, et combinaisons illégales à travers une expérience de décision lexicale visuelle couplée à l'électroencéphalographie.

*Résultats* : Les résultats de l'étude 1 suggèrent que les verbes français sont décomposés pour leur reconnaissance et que les verbes morphophonologiques ont une représentation phonologique abstraite. De plus, les verbes irréguliers ont des représentations séparées des radicaux allomorphiques dans le lexique mental. L'étude 2 a montré que les micro-classes dont les radicaux verbaux sont formés par la combinaison d'une racine et d'une voyelle thématique présentent un amorçage total et une décomposition complète, tandis que les micro-classes qui ont des processus allomorphiques présentent un amorçage partiel et des

représentations séparées ou médiées par des règles allomorphiques. Les résultats de l'étude 3 suggèrent qu'il y a des différences dans le traitement des mots avec un ou deux suffixes flexionnels, des différences dans le traitement entre les suffixes flexionnels de temps et d'accord, ainsi que des différences dans le traitement des traits morphosyntaxiques spécifiques activés par différents morphèmes. L'étude 4 a montré des différences entre les locuteurs débutants et avancés du français en L2 dans l'expérience sur les effets de fréquence et des petites différences dans les expériences de pseudoverbes et d'amorçage masqué. Cela indique qu'il y a des différences dans l'organisation des lexiques mentaux en fonction des niveaux de performance en L2 et en fonction de normes des fréquences. Aussi, même si les locuteurs bilingues ont des grammaires correspondantes, leur traitement grammatical en L2 est plus superficiel et limité. Enfin, l'étude 5 présente des données électroencéphalographiques avec des différences très fines dans les premières fenêtres de temps liées au traitement visuel et des différences spécifiques plus prononcées et tardives qui concernent le traitement des morphèmes lexicaux et des morphèmes fonctionnels.

*Conclusion* : D'une manière générale, ces résultats indiquent que les verbes français fléchis sont traités selon un modèle de mécanisme simple avec décomposition morphologique pré-lexicale pour la reconnaissance des mots. Ainsi, les mots seraient stockés sous forme décomposée dans le lexique mental. Les mots sont décomposés en morphèmes atomiques, les représentations morphémiques sont activées dans le lexique mental, puis les constituants de mots sont recombinaés pour la vérification et la reconnaissance du mot. De plus, ce travail suggère qu'il existe un traitement différent pour les morphèmes lexicaux et les morphèmes fonctionnels. Les verbes fléchis sont premièrement décomposés en radicaux et suffixes flexionnels, à partir de la forme des mots basés sur la systématique du système flexionnel. Ensuite, l'accès au morphème lexical est réalisé à travers l'activation des traits sémantiques du radical et le traitement des morphèmes fonctionnels avec activation des traits morphosyntaxiques. Enfin, les morphèmes sont recombinaés pour la vérification et reconnaissance du mot. Ces résultats semblent compatibles avec les modèles décompositionnels en psycholinguistique et linguistique qui attribuent un rôle critique aux structures hiérarchiques grammaticales cognitives pour le traitement du langage.

**Mots-clés** : Psycholinguistique, Morphologie, Accès Lexicale, Reconnaissance des Mots, Flexion, Verbes, Traitement, Décomposition, Structure, Linguistique.



# Abstract

## **Mental Lexicon Architecture and Morphological Processing of French Verbs**

How words are recognized? How do we process word meaning? These questions have been pursued in lexical access and word recognition studies in the last half century of research in psycho-, neuro-, and linguistics. Morphological processing is an essential level of processing for information extraction during word recognition. In one extreme, full-entry models propose whole-word storage and post-lexical morphological processing based on paradigms; in the other extreme, decompositional models posit pre-lexical decomposition and morphemic activation based on rules; between then, dual-mechanism models consider two routes for word recognition, a whole-word associative and a combinatorial rule-based routes. In the present thesis, the morphological processing of French inflected verbs in visual modality in five studies was investigated. Study 1 researched the mental lexicon organization in function of surface and cumulative frequencies; Study 2 explored different stem formation processes; Study 3 investigated morphological operations in the inflectional suffixes; Study 4 tested the verbal morphological processing in L2 French speakers; and Study 5 tested verbal violations coupled with electroencephalography acquisition. The results suggest that all inflected French verbs are processed by a single-mechanism model with pre-lexical morphological decomposition for lexical activation and word recognition. Different processing procedures are proposed for the lexical and functional morphemes. Words are decomposed in atomic morphemes, morphemic representations are activated in the mental lexicon, and word constituents are recombined for word verification.

**Keywords:** Psycholinguistics, Morphology, Lexical Access, Word Recognition, Inflection, Verbs, Processing, Decomposition, Structure, Linguistics.





# Thesis Title and Laboratory Address

Mental Lexicon Architecture and Morphological Processing of French Verbs

Architecture du Lexique Mental et Traitement Morphologique des Verbes Français

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# Abbreviations

~: allomorphy

&: and

|: or

/phono/: phonological description

[morpho]: morphological description

<ortho>: orthographic description

√: root

AAM: Augmented Addressed Morphology

Agr: agreement

BA: Brodmann area

BP: Brazilian Portuguese

C-I: conceptual-intentional

CM: Construction Morphology

CP: clause phrase

DM: Distributed Morphology

DS: deep structure

EEG: electroencephalography

ELAN: early left anterior negativity

EPP: Extended Projection Principle

fMRI: functional magnetic resonance image

FR: French

IFG: inferior frontal gyrus

InflP: inflectional phrase

IP: Item-and-Process

L1: first language

L2: second language

LAN: left anterior negativity

LF: logical form

LMBM: Lexeme-Morpheme Base Morphology

MEG: magnetoencephalography

MM: Minimalist Morphology

MP: Minimalist Program

MS: morphological structure

MTG: middle temporal gyrus

NDL: Naïve Discriminative Learning

OD: Obligatory Decomposition

PDP: Parallel Distributed Processing

PF: phonological form

ROI: region of interest

RT: reaction time

SM: sensory motor

SMT: Strong Minimalist Theory

Spec: specifier

SS: surface structure

STG: superior temporal gyrus

T: tense

Th: theme vowel

UG: Universal Grammar

v: stem

VWFA: visual word formation area

W&R: Words and Rules

WP: Word-and-Paradigm

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# 1 Introduction

“Experimental work related to morphology must take some theoretical commitments; it is not possible to be agnostic over issues such as whether words decompose into morphemes” (Marantz, 2016, p.154)

How do we recognize words? How are words stored? How are words processed during reading? These have been major questions in the last half-century of psycholinguistic, neurolinguistic, and linguistic research on human language. Two competing models are that words are stored and recognized through their whole word form and that words are stored and recognized through their morphological constituents. The former hypothesis implies substantial memory resources and redundant information, and the latter implies greater computational resources and symbolic manipulation; alternatively, dual-mechanism models postulate the use of both mechanisms for word processing and lexical access (Clahsen, 2006a).

The present thesis investigates how speakers recognize words by means of morphological processing. More specifically, how French (FR) verbs are processed during visual word recognition was investigated. We performed five studies to research different aspects of the verbal inflectional processing. Our main results are in line with single-mechanism models with morphological decomposition. Below, we discuss in detail the theoretical and methodological aspects of this work, as well as the implications of and conclusions drawn from our results. However, first, we introduce some important ideas about language, morphology, and visual word recognition.

One of the biggest mysteries of human nature is the human capacity to use language as a complex instrument of communication. Language is considered here as the unique human capacity to use a finite set of units, words, to produce an infinite set of sentences and complex ideas through symbolic manipulation (Chomsky, 1995). It is widely accepted that human language emerged approximately 50,000-100,000 years ago with the *Homo sapiens*. Recent research has provided evidence that the human language faculty evolved from a genetic mutation that rewired the brain, linking a conceptual-intentional (C-I) system of thought to a sensory-motor (SM) system of externalization. The human language faculty is characterized by the single Merge operation. The merge operation is the simplest binary operation of

representing two elements as a more complex one: merge X and Y has Z as the result, in the form  $Z = \{X, Y\}$  (Berwick, Friederici, Chomsky, & Bolhuis, 2013; Fitch, Hauser, & Chomsky, 2005; Hauser, Chomsky, & Fitch, 2002).

It seems that all modern languages evolved from a single language during the exodus of *Homo sapiens* from Africa. This means that all languages are subserved by the same general components and that cross-linguistic differences are surface differences underlain by a core Universal Grammar (UG) faculty (Bolhuis, Tattersall, Chomsky, & Berwick, 2014). These differences are mostly perceived at the phonological and syntactic levels, even if all languages explore a restricted subset of phonemes and syntactic constraints in their systems, that is, “from a general perspective of the structure of grammar, the variations in morphologies cross-linguistically can be seen as superficial variations on strong universal themes” (Marantz, 2016, p.156).

Therefore, morphology is the linguistic level that generates the interface between the phonological form and syntactic structure, interacting with the mental lexicon for interpretation of semantic/logical form. According to Beard (2006, p.60), “this is the function of morphology, which is the interface between the lexicon and syntax, on the one hand, and the phonological or sign output, on the other”, thus, morphology encodes different features of syntactic processing in the phonological form of a word. Different languages encode different parameters from the syntactic processing in the morphological level. Consequently, the word level is not the minimal linguistic meaningful sign but is instead a complex form that encodes syntactic, semantic, and phonological information for language processing and interpretation. It follows that morphology is not a component of UG but is rather a subcomponent of syntax that is manifested at the word level (Di Sciullo & Williams, 1988).

As introduced above, at one extreme, the Full-Entry Hypothesis proposes that each single word is stored in the mental lexical as a whole unit (Booij, 2010a; Jackendoff, 1975; Matthews, 1991), at the other extreme, the decompositional hypothesis proposes that words are the result of abstract morphemic representations computed in the mental lexicon (Bloomfield, 1933; Halle & Marantz, 1993; Siddiqi, 2009). It seems reasonable to say that the truth must be between these poles, as many investigations have suggested dual-mechanism models, however, the challenge has been to prove where this middle is and which characteristics and constraints define the morphological level in language processing and word recognition. In this thesis, we argue in favor of a decompositional hierarchical system of

representations and computations for language interpretation, “there is always a minimal computation in language processing” (Chomsky, 2015).

We remark the Granularity Mismatch Problem between linguistics and neurosciences, where linguistic computation involves fine-grained distinctions and explicit operations, and neuroscientific approaches operate in broader conceptual distinctions (Poeppel & Embick, 2005). We investigated the lexical access in a visual modality based on theoretical linguistic analyses and on the analyses of empirical evidence from psycholinguistic experiments. At the theoretical level, we based our analyses in the Strong Minimalism Theory (SMT) and Distributed Morphology (DM) (Chomsky, 1993; Halle & Marantz, 1993). Empirically, we applied five psycholinguistic studies with a visual lexical decision task to understand how word recognition is mediated by morphological processing (Marslen-Wilson, 2007; Rastle & Davis, 2008; Taft, 1991).

In the following, section 1 describes the objectives, justification, questions, hypothesis, and studies of the present thesis; section 2 reviews the theoretical background; section 3 presents the five empirical studies in the form of articles; section 4 extends the general discussion; section 5 presents a model of morphological processing; and section 6 summarizes the conclusions from this thesis.

## 1.1 Brief Background

The “past-tense debate” promoted the development of studies on the morphological processing and mental lexicon representations. This was/is a theoretical and empirical discussion about the nature of the storage of the mental lexicon and processing that originated from the differences between regular and irregular words (e.g., play/played, drink/drank/drank) (Clahsen, 2006; David Embick & Marantz, 2005; Halle, 2000; MacWhinney, 2005; Marslen-Wilson & Tyler, 1998; McClelland & Patterson, 2002a, 2002b; Pinker & Prince, 1988; Pinker & Ullman, 2002b, 2002a; Rumelhart & McClelland, 1986; Seidenberg, 2006). Recent findings in psycho- and neuro-linguistics have shown that the morphological processing has an important role in visual word recognition. These studies have mainly investigated morphological processing regarding differences in the orthographic and semantic activations (Crepaldi, Rastle, Coltheart, & Nickels, 2010; Devlin, Jamison, Matthews, & Gonnerman, 2004; Feldman, O’Connor, & Del Prado Martín, 2009; Lavric, Elchlepp, & Rastle, 2012) or distinguishing syntactic, morphosyntactic, and morphological

processes (Boeckx, Martinez-Alvarez, & Leivada, 2014; Bozic, Marslen-Wilson, Stamatakis, Davis, & Tyler, 2007; Leminen, Jakonen, Leminen, Mäkelä, & Lehtonen, 2016; Marantz, 2016). However, the results and models proposed remain contradictory, and the debate seems to be far from over, especially when we contrast cross-linguistic differences presenting specific aspects of morphological processing (Poeppel & Embick, 2005).

Studies using large corpora have shown that approximately 40% of lexical decision reaction time (RT) latencies can be explained by frequency predictors, reaching 45% with additional lexical information, such as word length (Balota et al., 2007; Brysbaert & New, 2009; Ferrand et al., 2010; Keuleers, Diependaele, & Brysbaert, 2010; Keuleers, Lacey, Rastle, & Brysbaert, 2012). We believe that at least part of the remaining 50% of human behavior in lexical decision and word recognition might be explained by grammatical factors, such as morphological processing. Three main characteristics in human language are recursivity, creativity, and productivity (Matthews, 1991). Speakers create words from recursive properties in a creative way from productive processes. Morphology directly reflects these properties; that is, morphemes are combined in hierarchical recursive structures for word processing; creativity gives rise to the creation of new words, structures, and representations; and productivity establishes useful, recurrent, and regular processes according to the language parameters (Spencer, 1991).

The Mirror Principle states that morphology has a direct correspondence to syntax, where syntactic information can be differently encoded at the word level according to the syntactic structure and the speaker's intention (Baker, 1985). Therefore, morphological cross-linguistic differences show that while some languages express certain types of information with affixation, other languages express that information using single words. It follows that languages differentiate between lexical morphemes and functional morphemes, as for example Finnish and Mandarin. Although the former is an agglutinative language with rich morphology that encodes much information in the word form, the latter is an isolating language with poor morphology, and it realizes each lexical and functional morpheme in an independent phonological word. Synthetic languages realize both morphemes within the word and can be divided into fusional languages, such as Romance languages, which have a single suffix expressing multiple features, and agglutinative languages, which assemble long sequences of functional suffixes with their specific features in one phonological word (Beard, 1995; Spencer, 1991).

Lexical morphemes are the root and stem morphemes that form the “open classes” and must anchor their phonological realization and semantic concept; in contrast, functional morphemes are affixes and grammatical words (i.e., pronouns, prepositions, articles, auxiliary verbs) that form the “closed classes” and allow large cross-linguistic variation following general principles of phonological realization. Therefore, it follows that some languages have either more morphology with functional morphemes as affixes or less morphology with functional morphemes as single words. Functional morphemes express sets of grammatical features central to the grammatical system; thus, roots must be combined with functional morphemes to be used in sentences because it is this combination that anchors the phonological word (Embick & Noyer, 2007; Harley & Noyer, 1999). Then, functional morphemes become phonologically realized either by combining with a root or on their own, possibly together with other functional morphemes. In general, each morpheme determines a bit of phonological content, perhaps even phonologically null morphemes (Marantz, 2016).

Aside from the natural human language faculty, biological, developmental, and cultural aspects and differences play an important role in first-language (L1) acquisition during babyhood and late second-language (L2) acquisition during adulthood (Clahsen & Felser, 2006; Costa & Sebastián-Gallés, 2014). In non-native speakers, the critical period for language acquisition, neuronal plasticity, and prior language knowledge must be considered to better understand how these factors impact lexical access, promoting insights about the functioning of human language, psychology, cognition, and brain (Friederici, Steinhauer, & Pfeifer, 2002). Thus, language and morphological processing becomes an avenue for the study and understanding of human thought. The present thesis aims to investigate the morphological processing through a computational perspective to understand how French speakers store and process inflected verbs.

## 1.2 Objectives

The main objective of the present thesis is to investigate the visual word recognition mediated by morphological processing. In particular, we aim to test the lexical access of French inflected verbs in the visual modality. The secondary objectives are to understand the following: 1) morphological decompositional mechanisms, 2) morphological hierarchical structures, 3) mental lexicon representations, and 4) morphological operations for word recognition.

Further, our goal is to investigate and compare the morphological processing from different perspectives: 1) L1 morphological processing, 2) L2 morphological processing, and 3) electroencephalographic (EEG) time-course during morphological processing. Our objective is to contribute to a better understanding of word recognition, mental lexicon representations, and grammar processing.

The innovation in this thesis is that we attempted to narrow the divide between linguistics and psycholinguistics. To investigate word recognition in French verbal inflection, we used various experimental protocols such as lexical decision, cross-modal priming, masked priming, pseudoverbs, EEG analyses, and L1/L2 experiments. Additionally, we researched separately the stem lexical morphemes and the inflectional suffixes functional morphemes during visual word recognition.

## 1.3 Justification

Language complexity is the main capacity that distinguishes humans from other animals; this capacity is based in the memory system (mental lexicon) and grammar (syntax). Thus, understanding the function and processing of language becomes an obligatory step towards a better understanding of the nature of human language faculty. To that end, this thesis aims to verify a series of grammar-processing principles at the morphological level through psycholinguistic experiments in visual word recognition.

Understanding the nature of morphological processing and word formation is a window to the understanding of the mental lexicon and grammar; it has been a major field of research in the last several decades, and results have accumulated in favor of early visual orthographic processes for lexical access. Thus, this research can help to better understand the visual orthographic system in word recognition in dyslexic populations, can give insights for didactic purposes such as L1 and L2 teaching methods and language courses, and can inspire a broader understanding of the morphological processing in word recognition.

## 1.4 Questions

The main questions that drive this thesis are as follows: 1) How is verbal inflection processed at the morphological level? 2) How are verbs stored and accessed in the mental lexicon? 3) Which kind of model underlies French verbal inflectional processing? Is it in

agreement with the findings for other Romance languages? 4) What is the time-course of verbal inflectional processing? 5) How does morphological processing occur in French as L2?

Further, each experimental chapter presents different and specific questions related to each study. Naturally, each study yielded new questions, which were investigated in the subsequent study or were suggested for further research.

## 1.5 Hypothesis

The basic hypotheses that are being considered here are as follows: H0 is that all words are stored as whole units in the mental lexicon; our H1 is that morphemes are the atomic units in the mental lexicon and that word recognition is mediated by morphological processing; H2 posits dual-mechanism models for whole-word and rule-based word recognition; and H3 suggests Parallel Distributed Processing (PDP) for word activation.

Concerning late bilinguals: H0 states that beginner and advanced speakers present clear differences in word processing and that advanced speakers show behavior similar to that of native speakers. Our H1 is that L1 and L2 from morphologically close languages facilitates grammar processing, resulting in small differences between beginner and advanced speakers but large differences between late bilinguals and native speakers.

Regarding the EEG time-course: H0 states that there are no early differences (N1-P2) between the different types of (pseudo)verbal violations but that there are differences in the N400 and P600 for violated forms; our H1 states that there are early N1-P2 and LAN modulations in illegal forms, as well as N400 differences regarding stem access and P600 differences regarding morphological rule violations; and H3 posits specific differences in the N1-P2, LAN, N400, and P600 for the different (pseudo)verbal violations tested.

Afterwards, the experimental chapters each present their current and specific hypotheses and predictions about the experiment and manipulation being tested in each study. Our aim was to develop and test specific hypothesis in more detail through the evolution of the studies and materials.



## 1.6 Studies

Study 1, “Frequency Effects”, used one experiment to investigate different frequency effects by manipulating between high and low surface frequency and high and low cumulative frequency in fully regular verbs, morphophonological verbs, and irregular verbs. The main results suggest an obligatory decompositional model with atomic representations in of the fully regular verbs, underlying abstract phonological representations in morphophonological verbs, and allomorphic stem representations in the irregular verbs (Estivalet & Meunier, 2015a).

Study 2, “Stem Formation”, used two experiments, one with cross-modal priming and another with 52 ms masked priming, to investigate the stem formation of French verbs from the 1st class with fully regular verbs and different 3rd micro-classes with irregular verbs. The general results suggest a single mechanism model with full decomposition and root-based representations for all French verbs (Estivalet & Meunier, 2016).

Study 3, “Morphological Operations”, applied two experiments to characterize the morphological operations on verbal inflectional suffixes and specific morphosyntactic features from tense and agreement morphemes. The results suggest a decompositional model with different processes for stem, tense, and agreement morphemes according to hierarchical structures and morphophonological processes (Estivalet & Meunier, 2016b).

Study 4, “Bilingual Morphological Processing”, applied Study 1 and a previous version of the experiment from Study 5 in speakers of French as L2 with Brazilian Portuguese (BP) as L1. The results were analyzed between beginner and advanced speakers and suggest different lexicon organizations regarding frequency norms in Experiment 1 and no differences between beginner and advanced speakers regarding (pseudo)verbal violations processing in Experiment 2. The results were also analyzed in comparison to the native speakers’ results.

Study 5, “Electrocircuited French Pseudoverbs”, applied one experiment coupled with EEG on morphological violations to investigate the processing of different types of (pseudo)verbal structures and violations: legal, only stem, only suffix, illegal, and nonword, with one or two inflectional suffixes. Overall, the violations are differently processed regarding the access of the lexical morpheme and functional morphemes, suggesting early and automatic morphological decomposition for word processing and recognition (Estivalet & Meunier, 2016c).

In all experiments performed, participants were between 18 and 42 years old, right-handed, had no cognitive or language impairments, and gave written consent to participate in the experiments. Participant groups were always composed of equal numbers of men and women. Bilinguals were controlled in L2 proficiency through the following: 1) time of L2 contact, 2) time of L2 study, and 3) time living in France. Most of our participants were students from the *Université de Lyon* and had completed at least 12 years of education. For the application of the empirical experiments in human participants, our project of research received authorization from the *Comité de Protection des Personnes Sud-Est II*, IRB: 00009118, as shown in Appendix A. An example of the written consent signed by all the participants to perform our experiments is shown in Appendix B.

For the construction, application, and data acquisition of all experiments, we used the software E-Prime® 2.0 Professional (Psychology Software Tools, Inc., Sharpsburg, PA, USA) (Schneider, Eschman, & Zuccolotto, 2012). We explored automatic matching of words and nonwords with the software Match (van Casteren & Davis, 2007); to pseudo randomize the experimental lists, we used the software Mix (van Casteren & Davis, 2006). For the statistical analysis, we used the software R version 3.1.2 (R Foundation for Statistical Computing, Vienna, Austria) (R Core Team, 2014) and the following R packages: ‘car’, ‘lme4’ (Bates, 2005), ‘lmerTest’, ‘languageR’ (Baayen, 2013), ‘psych’ (Revelle, 2015), ‘vwr’ (Keuleers, 2013), and ‘zipfR’ (Evert, 2015). We also used the Matlab® software (MathWorks, Inc., Natick, MA, USA) with the FieldTrip toolbox (Oostenveld, Fries, Maris, & Schoffelen, 2011) for the EEG analyses. A flowchart of the five empirical studies performed in the present thesis is shown in Figure 1.

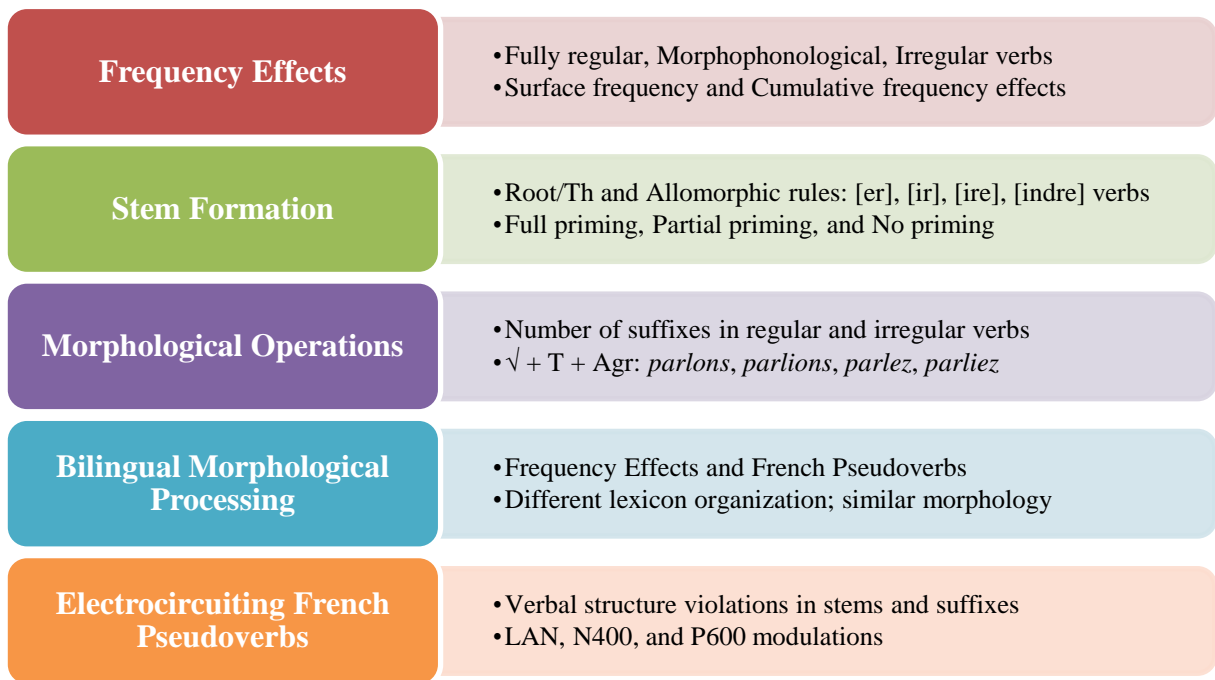


Figure 1 – Flowchart of the five empirical studies performed in the present thesis.

## 2 Theoretical Background

In this main section, we present the theoretical background from this thesis, reviewing the linguistic principles, morphological processing and models, and empirical results on visual word recognition and morphological processing. It is presented in section 2.1 a general view of language and linguistics, 2.2 the basis for word recognition in visual and auditory modalities, 2.3 the main processes and implications of morphological processing, 2.4 the single-route models, 2.5 the connectionist models, 2.6 the dual-route models, 2.7 the French verbal system, 2.8 the bilingual morphological processing, and 2.9 a sum up of the whole Section 2.

### 2.1 Language

“The principles that determine the nature of the mental representations and the operations that apply to them form a central part of our biologically determined nature. They constitute the human language faculty, which one might regard as an “organ of the mind/brain” (Chomsky, 1988, p.131)

What is language? Language is considered here as the human capacity to communicate using complex signs. How does language work? Many philosophers have addressed this question, including Panini’s grammar, Plato’s *Cratylus* (Platão, 2001), Aristotle’s grammar, the Port-Royal Grammar (Arnauld & Lancelot, 2010), Saussurean Structuralism (Saussure, 1997), and Chomsky’s *Generative Grammar* (Chomsky, 1965). How has language evolved? Paleontological discoveries have shown that approximately 50,000 years ago, the human species already had the modern vocal tract and were capable of producing the same sounds as today. A common and discussed hypothesis is that a single genetic mutation rewired the human brain, allowing the emergence of the language faculty. This rewiring is probably what is known as the arcuate fasciculus, which is the large tract of fibers linking anterior and posterior regions in the human brain (Broca’s and Wernicke’s areas) (Friederici, 2009; Marslen-Wilson & Tyler, 2007). This rewiring contributed to the SM control of the vocal tract, lips, tongue, and diaphragm. This capacity probably facilitated human survival based on

their advantages in organization, planning, intention, and representation, which were further disseminated to their descendants, constituting groups of humans with a large capacity for complex thought and the externalization of those thoughts. This evolution matches with the first cave paintings discovered in Africa, supporting the emergence of symbolic representations and the birth of the first natural language, which has been modified since the exodus from Africa (Bolhuis et al., 2014; Fitch et al., 2005).

The human language faculty can be characterized by a simple binary Merge operation, which takes exactly two elements, X and Y, to construct another one, Z:  $Z = \{X, Y\}$ . This single operation gave rise to the recursive computational system in natural languages. Thus, language evolved from a system of symbolic representation, taken as the semantic structure in the logical form, which can be externalized by speech or sign language, yielding the phonological structure, in different recursive hierarchical pathways, defining the syntactic structure (Chomsky, 2015). Consequently, the emergence of morphology comes from the merge operation, which allows the combination of two or more abstract signs in one phonological word; that is, morphology mediates the merge between phonemes to the merge between lexical and functional constituents (Marantz, 1984).

Nevertheless, at least three hypotheses should be considered for language evolution considering general and specific domains; that is, the faculty of language can be characterized in broad (FLB) and narrow (FLN) senses, respectively. “FLN is the abstract linguistic computational system alone, independent of the other systems with which it interacts and interfaces. FLN is a component of FLB, and the mechanisms underlying it are some subset of those underlying FLB” (Hauser et al., 2002, p.1571), as shown in Figure 2. The first hypothesis states that FLB is strictly homologous to animal communications; the second hypothesis proposes that FLB is a derived, uniquely human adaptation for language (Lieberman, 2015); and the third hypothesis states that only FLN is uniquely human, having recently evolved in our species (Bolhuis, Tattersall, Chomsky, & Berwick, 2015).

“A language consists of a lexicon and a computational system. The computational system draws from the lexicon to form derivations, presenting items from the lexicon in the format X-bar theory” (Chomsky, 1993, p.19). Yang (2013) showed that corpora simulation and monkey language acquisition cannot be simulated as the phylogeny and ontogeny of human language, supporting the idea that language is a domain-specific system developed in the first years of babyhood. Another study in sign language from children showed the innate

emergence of many linguistic principles as an underlying computational system for the expression of complex thoughts throughout signs (Goldin-Meadow, 2005).

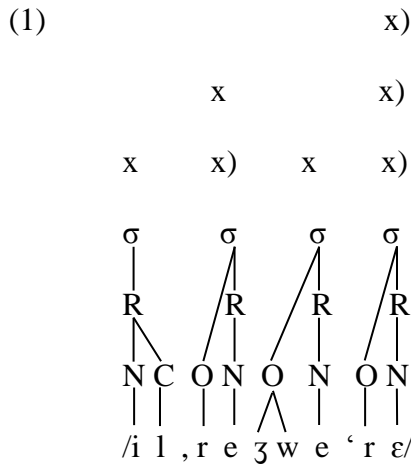
Figure 2 - Organism external and internal factors related to the language faculty. FLB includes sensory-motor, conceptual-intentional, and other possible systems; FLN includes the core grammatical computations recursion (Hauser et al., 2002).

### 2.1.1 Linguistic Model

The Port-Royal Grammar (Arnauld & Lancelot, 2010) is considered the first UG to describe the language functioning in general principles. Language, as we know, must be characterized on at least two levels: a phonological level that describes the externalization of language and a semantic level that reflects the internal interpretation. Thus, the speakers of a language must learn the grammar, the morphemes, and the constraints on their combinations and rules for their phonological realization and semantic interpretation, accounting for the relationships between form and meaning (Marantz, 2016). In this sense, from a general psycholinguistic view, language can be described on different levels according to (1), adapted from Jackendoff (2000).

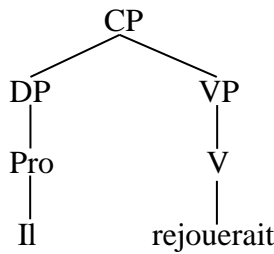
This descriptive representation is supported by specific linguistic sub-theories regarding its specific levels: 1) prosodic, syllabic, and phonological description defined by the

Autosegmental and Metrical Phonology theory (Goldsmith, 1990), 2) syntactic description defined by the MP (Chomsky, 1995), and 3) morphological description defined by the DM (Halle & Marantz, 1993). These theories were developed further by Halle and Idsardi (1996) on the phonological level, Chomsky (2015) on the syntactic level, and Siddiqi (2009) on the morphological level.

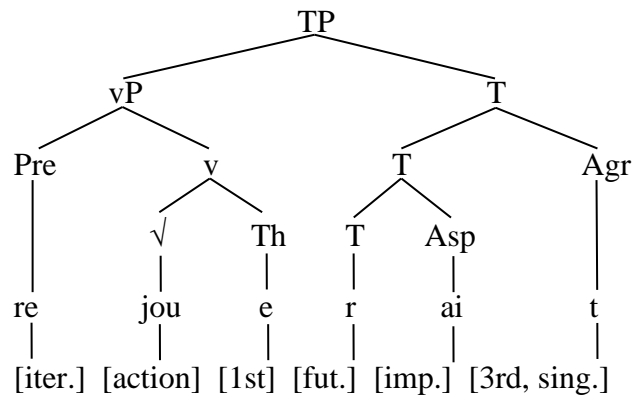


*Il rejouerait* ‘He would play again’

[[[Il]<sub>Pro</sub>]<sub>DP</sub>[[rejouerait]<sub>V</sub>]<sub>VP</sub>]<sub>CP</sub>



[[[re]<sub>Pre</sub>][jou]<sub>v</sub>[e]<sub>Th</sub>]<sub>vP</sub>[[[r]<sub>T</sub>[ai]<sub>Asp</sub>]<sub>T</sub>[t]<sub>Agr</sub>]<sub>T</sub>]<sub>TP</sub>



Prosody
Syllable
Phonology
Orthography
Syntax
Morphology
Features

### 2.1.2 Morphophonology to Morphosyntax

Phonology and semantics can only be explored in a realistic way when the notion of generative syntax is incorporated, providing the possibility of infinite expressions of thoughts. Morphology is the level of the interactions between phonology and syntax. While morphophonology stands for the relationships between phonology and form (Embick, 2013), morphosyntax stands for the relationships between syntax and form in hierarchical structures (Baker, 1985). Thus, more than the study of words, morphology is the study of the local relationships between parts of words interrelated with other linguistic levels.

Regarding the phonological level, a small set of articulatory representations can be combined to create the variety of language sounds; the phonological features define the phonologies of languages across the world. Consequently, basic phonological cortical principles are generic, with further cross-linguistic specification for specific articulatory parameters (Bouchard, Mesgarani, Johnson, & Chang, 2013; Mesgarani, Cheung, Johnson, & Chang, 2014). The phonological form is submitted to contextual pronunciation; thus, morphophonological constraints for pronunciation are determined by local relations.

Regarding the syntactic level, different languages encode different information at the word level (Anderson, 1992; Baker, 1985; Spencer, 1991); whereas Mandarin is an isolating language with poor morphology, Finish is an agglutinative language with rich morphology. Notably, languages mainly differ in regard to their morphological level, which is the level at which the specific language parameters take form (Beard, 1995; Chomsky, 1995). Therefore, morphological differences must directly reflect syntactic differences (and vice versa); furthermore, this theory restricts the possible morphological structures and how they may be related to the possible syntactic structures in each language (Baker, 1985).

### 2.1.3 Minimalism

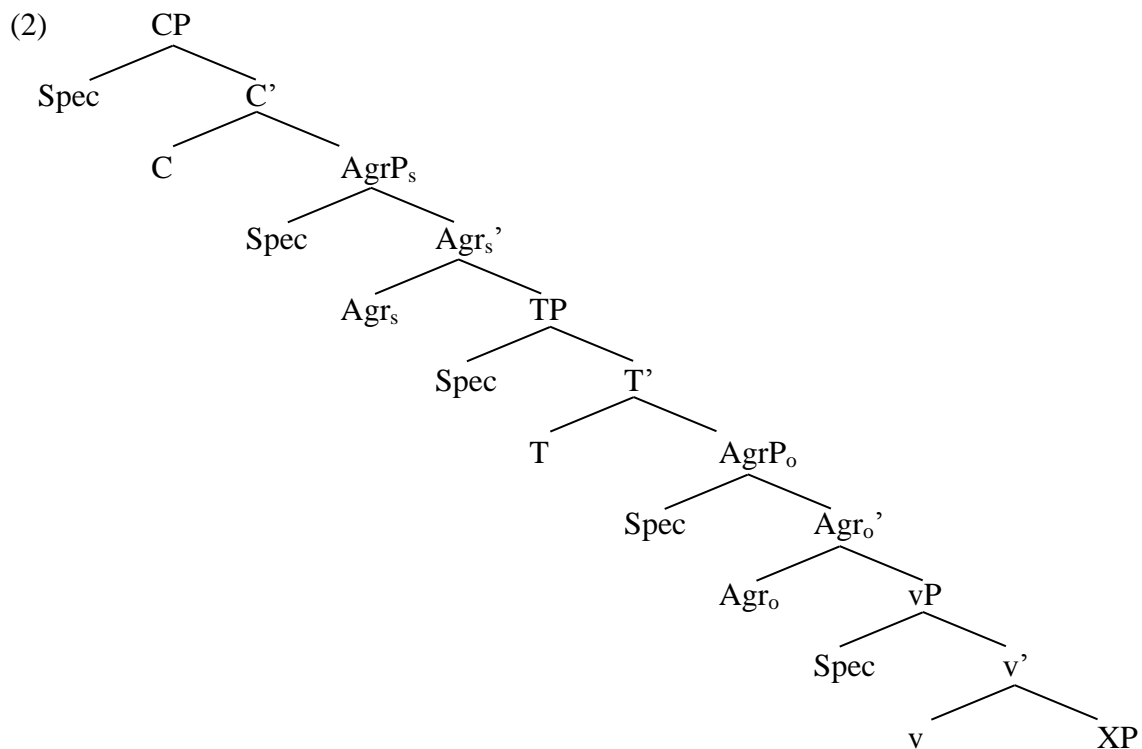
Historically, the development of linguistics can be summarized in small steps in the descriptive and explanatory adequacies until the 20th Century. Then, in the beginning of the 20th Century, Saussure established linguistics as a scientific field, with its proper levels of analysis, description, and interactions with other scientific fields, such as semiotics, sociology, anthropology, and biology (Saussure, 1997). Finally, Chomsky revolutionized linguistics from the 1950s until recently with the Generative Grammar (Chomsky, 1957, 2015). The Generative Grammar received a large apparatus and a complex theoretical



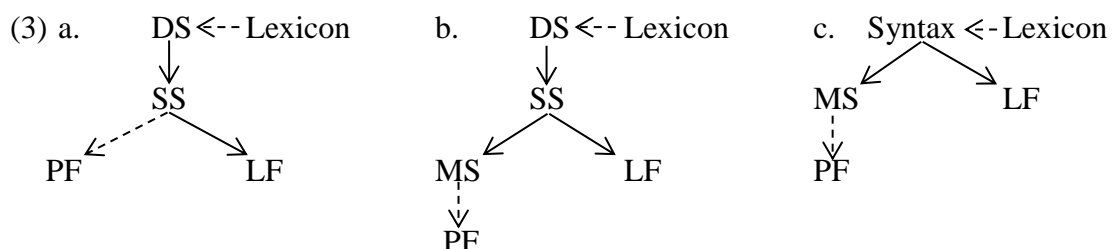
framework in its early years; however, the most recent frameworks simplified the descriptive and explanatory machinery, giving place to more psycholinguistic and neurocognitive hypotheses. As advanced by Chomsky (1980, p.1-2), “many new phenomena have been studied, and there has been some progress, I believe, towards a more principled theory of grammar with far more restricted descriptive devices and some abstract principles that are, on the one hand, rather natural for a system of mental computation, and on the other, genuinely explanatory in that they interact to ground and unify a number of properties of rule systems that have been discovered”. The large amount of descriptive evidence accumulated from better-studied languages showed that the apparent idiosyncrasies or exceptions disappear upon deeper investigation. However, significant linguistic principles are not observed phenomena and can only be confirmed or refuted indirectly through the construction of grammars, going beyond the accumulation of observations.

Concerning the investigation of verbal inflection in word processing, the theory of inflection provides natural mechanisms for morphological processing, in which the basic structure of the clause should be enriched with the morphological nodes pertinent to a specific language grammar, as represented in (2) (Chomsky, 1993). Considering our main interest in understanding the morphological nature of the verbal inflection in French and how word formation is processed, the structure in (2) contains the clause phrase (CP), subject agreement ( $Agr_s$ ), tense phrase (TP), verbal phrase (vP), and object agreement ( $Agr_o$ ) nodes. Specifier (Spec) is the place for syntactic movement through the Move  $\alpha$  syntactic operation, the subject and object agreements present a set of phi-features (person, number, and gender) (den Dikken, 2011), the vP is the node for the stem formation, and the TP is the locus of the speakers’ situational and intentional inflection, being equivalent to the inflectional phrase (InfP) (Emonds, 1978; Pollock, 1989).

Following the syntactic movements of morphemes for word formation in verbal inflection, according to Beard (1995, p.137), “[Principles and Parameters Theory] (P&P) assumes that each of these [phi-] features receives its own projection, which is filled with some morpheme during lexical insertion. v is then raised through those positions to Infl, amalgamating with any bound morphemes occupying head positions intermediate between v and Infl. Affixes not accounting for by amalgamation combine with v by affix-hopping or lowering”, resulting in a general morphological hierarchical structure for verbal inflection.



Early frameworks of the Generative Grammar proposed that language should present the following components: 1) lexicon, 2) phonological form (PF), 3) logical form (LF), and 4) deep structure (DS), relied by 5) surface structure (SS), according to the Standard Theory (3a) (Chomsky, 1965). Further formulation of the language architecture including the morphological structure (MS) was adopted in the DM framework, as shown in (3b) (Halle & Marantz, 1993). Finally, recent formulation with the SMT eliminated the DS and SS in a simpler architecture, as shown in (3c) (Arregi, 2000).



### 2.1.4 The Mental Lexicon

The “mental lexicon” is broadly defined as “the store of words in a person’s mind”, but we have to clarify the definitions of “store” and “mind”. The mental lexicon is broadly

understood as the speaker's memory related to language representations, that is, where the words are stored. However, storage should not be taken as the store of whole word units, and mind should be understood as the specific brain mechanisms that encode and process this information (Jackendoff, 2002). The mental lexicon has an abstract and complex structure for the representation and access of words through semantic features for syntactic constraints, such as [+/-animate], [+/-human], [+/-N], [+/-count], [+/-abstract], [+/-common]. It follows that word classes can be defined by two features, as shown in (4) (Chomsky, 1965). In the DM, the lexicon was distributed in three lists: morphosyntactic features, vocabulary items, and encyclopedia, where the only place for word formation is the syntax (Siddiqi, 2010).

(4) Word classes as defined by N and V features

	+V	-V
+N	Adjectives	Nouns
-N	Verbs	Prepositions

Concerning the nature of the phonological and lexical representation, models of lexical access have stated simple representations consisting of the linear concatenation of segments without internal structure. These segments are implicitly assumed to be phonemes; however, unlike phonological assumptions, these phonemes are seen as wholes rather than as composed of features. Lexical representations are similarly misconceived as unstructured string of segments. Lexical access is then assumed to consist of sequential mapping between these two representations (Frauenfelder & Lahiri, 1992).

Therefore, the mental lexicon must have much more complex phonological (and orthographic) and lexical representations interacting with the computational system to dynamically activate the mental representations (Dijkstra, 2007). Is the mental lexicon composed of whole word representations? Or is it where phonological, syntactic, and semantic information streams interact through linguistic computations? The answer is not simple, but it seems that both responses are correct. Recent morphological models have proposed a continuum between rule-based, lexical, schematic, and syntactic representations stored in the mental lexicon (Booij, 2010a; Hay & Baayen, 2005).

Much of this debate was absorbed by the Split Hypothesis, in which derivation and inflection are different morphologies; whereas the former is conceived as whole word units in

the mental lexicon, the latter is underlain by grammatical computations (Beard, 1995). This hypothesis was invoked by Chomsky (1970), opening the discussion of whether syntactic operations have access to the internal structure of lexical items, originating the Lexicalist Hypothesis. The Lexicalist Hypothesis comes in two flavors; in the weak version, there is an interaction between syntax and word formation (Halle, 1973); in the strong version, syntax has no access to lexical items, and syntax and morphology are thus strictly independent. While the Weak Lexicalist Hypothesis includes a general combinatorial system that operates at all linguistic levels, the Strong Lexicalist Hypothesis posits individual and separate components for the syntactic processes and lexical processes during language interpretation.

In this sense, the Strong Lexicalist Hypothesis considers the Full-Entry Hypothesis (Jackendoff, 1975), stating that all words (i.e., derived, composed, inflected, chunks, and idioms) have their entries in the mental lexicon and are related by lexical redundancy rules. This kind of representation follows the Word-and-Paradigm (W&P) architecture of grammar, in which words are represented and activated based on paradigms and word relationships (Blevins, 2013; Matthews, 1965; Robins, 1959), as in the Parallel Representation Morphology (Jackendoff, 1997) and the Construction Morphology (CM) (Booij, 2010a), which consider different phonological, syntactic, and semantic linked representations in the mental lexicon. The Weak Lexicalist Hypothesis partially accepts the syntax interaction with morphology in the case of inflection, such as in the A-Morphous Morphology (Anderson, 1992) and Minimalist Morphology (MM) (Wunderlich & Fabri, 1995), also in a W&P architecture; or it completely integrates the syntactic penetration in the word morphology, such as in the DM (Halle & Marantz, 1993) and Lexeme-Morpheme Base Morphology (LMBM) (Beard, 1995) in an Item-and-Process (IP) architecture of grammar, in which words are processed through rules and combinatorial processes (Bauer, 1979; Hockett, 1954).

Moreover, the dichotomy between derivation and inflection is considered a theoretical fallacy that emerged from the Western languages and should be considered as a continuum of word-formation processes (Beard, 1995; Booij, 1993; Matthews, 1991). However, empirical research has presented divergent results between inflectional and derivational processing (Badecker & Caramazza, 1989; Bozic & Marslen-Wilson, 2010; Marslen-Wilson & Tyler, 1997). Furthermore, this distinction remains interesting for cross-linguistic analyses and processes that take place on word classes (derivation) and word features (inflection) (Bybee, 1985).

Independently of the representation and process that activate words, the general properties of a lexical entry in the mental lexicon can be represented as in Figure 3 (Levelt, 2000). The semantic and syntactic features define the meaning of the word, and the morphology and phonology define the form of the word; the pointer is the interface between abstract representations and lexical items.

Figure 3 - Constitution of a lexical entry in the mental lexicon (Levelt, 2000).

## 2.2 Word Recognition

“Experimental psychology has traditionally had limited tolerance for highly complicated explanations; while tastes may be changing a bit, complexity continues to arouse suspicions, and it should. [...]. No one promised that science would be easy” (Besner & Johnston, 1992, p.311)

We note that most linguistic models clearly differentiate the SM and C-I components, where the latter is implied in the thought, language content and interpretation and the former in the externalization and linearization interface (Anderson, 1992; Beard, 2006; Bloomfield, 1933; Chomsky, 1995; Jackendoff, 2002; Saussure, 1997). In contrast, psycholinguistic models sometimes do not consider this distinction, proposing models with no clear divisions between these modules (Baayen, Milin, Đurđević, Hendrix, & Marelli, 2011; Crepaldi et al., 2010; McClelland & Rumelhart, 1981; Perry, Ziegler, & Zorzi, 2014; Seidenberg, 2007). Linguistics considers phonemes, syllables, stress, morphemes, words, chunks, sentences, and linguistic features as linguistic levels; in contrast, bigrams and trigrams are not a linguistic level but instead are abstractions from the orthography. Thus, for the SM module, the minimal linguistic units are phonemes, and the maximal projection is prosody; in the C-I module, the minimal linguistic information units are morphemes, and the maximal projections are complex thoughts in a syntactic recursive structure. This distinction should be kept in mind when investigating fine-grained SM processing and hierarchically structured C-I processes.

We can summarize some main finding and effects already found in lexical decision tasks, where the participants should respond if a word exist or not: ‘yes’ responses are a) faster for high frequencies than for low frequencies (Burani, Salmaso, & Caramazza, 1984; Estivalet & Meunier, 2015a), b) faster than ‘no’ latencies (Coltheart, Rastle, Perry, Langdon, & Ziegler, 2001), c) unaffected by orthographic neighborhood when words are of high frequency (Andrews, 1997), and d) facilitated by orthographic neighborhood when words are of low frequency (Taft, 1991).

### 2.2.1 Visual Processing

Visual information, such as location, size, shape, color, texture, direction, and speed, is the main information transduced by the retina to the primary visual cortex in the occipital lobe, which distributes these types of information to other brain regions (Purves et al., 2005). Sereno and Rayner (2003) describe the typical time-course of the visual processing during word recognition as measured by EEG. The first positivity (P1) at 50-100 ms after stimulus onset indicates that there is new visual information to be processed. The first negativity (N1) at 100-150 ms seems to be related to orthographic processing, and the P2 reflects the lexical search/activation. According to the authors, the lexical access occurs during 100-200 ms after onset, and at 250 ms, there is an instruction to perform a new saccade, that is, to move the reading to another word, as shown in Figure 4A.

Nevertheless, the lexical decision and motor activity for responses in lexical decision tasks or word production occur later, generally after 500 ms. Thus, what the authors call lexical access is actually the word-form activation in the SM, but the real access of the lexical properties of the word, such as semantic features and meaning, and morphosyntactic features takes place later, at approximately 250-550 ms (Rastle, Davis, Marslen-Wilson, & Tyler, 2000; Stockall, Stringfellow, & Marantz, 2004). Interestingly, Sereno and Rayner (2003) showed that significant frequency effects in RT between high- and low-frequency words are only tracked in the lexical decision task, and only minor differences can be observed in normal reading, as shown in Figure 4B.

Figure 4 - A) Time-course of word reading processing: one electrode over the left occipital temporal parietal region. B) Word frequency effects across experimental paradigms. HF: high frequency, LF: low frequency, and EM: eye movement (Sereno, 2003).

According to Price, Indefrey, and VanTurenout (2000), during the first visual processing stage, orthographic units are identified, then, information can proceed in two ways, based only on the orthography or based on the mapping of orthographic to phonological units. The extent to which the two codes are related depends on a number of factors, such as the writing system, reading skill, and the kinds of words. Pseudowords can only be read by mapping orthography to phonology.

The Dual-Route Cascade (DRC) is a model of reading aloud that incorporates the two routes for lexical access, one direct from orthography, which means that the activation of the whole word unit gives its phonetic form, and another maps different phonemes from graphemes, combining them to create the phonetic form (Coltheart et al., 2001). More recently, the Connectionist Dual Process Model of Reading Aloud (CDP+++), also inspired by the PDP architecture but with fewer parameters than other models, was implemented in French and produced satisfactory results regarding the pronunciation of irregular words in the grapheme to phoneme relationship (Perry et al., 2014). The Bilingual Interactive-Activation (BIA) model is in line with these connectionist models and was developed to investigate, simulate and understand the bilingual lexicon; especially, it include a higher node for specific language activation (Dijkstra & van Heuven, 2002; Jonathan Grainger & Dijkstra, 1992).

Figure 5 – Computational models of visual word recognition. IA: interactive-activation, LD: lexical decision, PI: perceptual identification, RA: reading aloud, R: natural reading, and MP: masked priming (Norris, 2013).



Norris (2013) presented a review of the word-recognition models, classifying them by kind of model, style of computation, tasks used for testing and/or simulating the model, phenomena researched, and corpora used, as shown in Figure 5. Interestingly, for this list, the author considered as the model of morphology the amorphous Naïve Discriminative Learning (NDL) model, which proposes direct access from orthography to semantics (Baayen et al., 2011).

It was recently shown that baboons can process orthography in the absence of prior language knowledge. The authors showed that trained baboons can discriminate English words from nonsense combinations of letters that resemble real words. The conclusions are that basic orthographic processing skills can be acquired in the absence of linguistic representations; it follows that even if baboons do not have a linguistic system, they perform pure orthographic processing as do humans; thus, the neural mechanisms underlying orthographic processing in the two species must be similar and therefore non-linguistic (Grainger, Dufau, Montant, Ziegler, & Fagot, 2012; Hannagan, Ziegler, Dufau, Fagot, & Grainger, 2014; Ziegler, Hannagan, et al., 2013), as shown in Figure 6.

Figure 6 - A) Accuracy for words and B) nonwords for blocks of 2,000 trials for each baboon. Baboons attained an accuracy level of about 75%. Error bars correspond to the 95% binomial confidence interval, which are also displayed in gray for chance performance.

Obviously, these results came with many commentaries and discussion along the lines of “what can we learn from monkeys about orthographic processing in humans?” (Frost & Keuleers, 2013). Another line of criticism showed that independently of letter, bigram, or

trigram consistency and frequency, the single ability to discriminate shapes of letters in specific positions can predict the results; a simple learning algorithm based on letter position in tetragrams was implemented, and the results showed that letter frequency and patterns are not necessary for recognizing words, which means that orthographic processing is not closely related to our ability to recognize real words (Bains, 2012). The authors responded with “what can we learn from humans about orthographic processing in monkeys?” and indicated the limits of their algorithm and materials ( Grainger, Dufau, Montant, Ziegler, & Fagot, 2012; Platt & Adams, 2012; Ziegler, Dufau, et al., 2013).

This study showed that the basic orthographic processing in baboons and humans seems to be based on the same mechanisms. In a way, it provided support for a clear separation of the SM system from the C-I language knowledge. The question is inevitable: Considering that baboons have a minimal C-I, if they had an arcuate fasciculus connecting anterior and posterior areas of the brain, could baboons talk? Further, would they encode *jouons/jouions* ‘we play/we played’ separately or using a rule? It is probably too early for a good answer. Nevertheless, the SM may be separated from the C-I system; while the former delivers proper information to other systems, the latter internally processes and interprets this information. Additionally, we note “the remarkable inefficiency of word recognition”, where identifying known visual words with contrast noise disturbs participants’ performance, and the word cannot be recognized as a whole unit but is recognized only when the letters are separately identifiable (Pelli, Farell, & Moore, 2003).

Functional magnetic resonance imaging (fMRI) was used in a series of studies about the role of the visual word formation area (VWFA) in the fusiform gyrus; the authors’ results “provide strong corroborating evidence for the hypothesis that reading acquisition partially recycles a cortical territory evolved for object and face recognition, the prior properties of which influenced the form of writing systems” (Dehaene & Cohen, 2011, p.254). In another study, the authors argued that the VWFA contains visual modality-specific and pre-lexical representations of visual words (Dehaene, Le Clec’H, Poline, Le Bihan, & Cohen, 2002). These findings are consistent with decompositional models of word recognition stating that sub-lexical representations are stored in the peripheral SM system (Taft, 1991).

In another study with masked priming experiments, the authors showed fMRI and EEG differences in cortical activations between visible and masked words, as shown in Figure 7. While visible words show more activation in the fusiform gyrus and parietal areas, masked words present reduced activation in the VWFA; in the ERP images, masked words show

reduced activation in the occipital lobe in the early time-window, no consistent frontal activation for lexical search/activation, and posterior spread activation in the late time-window. Again, these results support the VWFA being a visual area recycled for the processing of orthographic features.

Figure 7 – A) fMRI activations to visible and masked words and B) ERPs in response to visible and to masked words (Dehaene, Cohen, Sigman, & Vinckier, 2005).

### 2.2.2 Auditory Processing

The auditory processing in word recognition presents a larger consensus in the asynchronous processing of the input; thus, the language computations are dynamically linear in a serial parser, such as in the COHORT model (Marslen-Wilson, 1987). It was proposed that reading should be also considered as something like the COHORT model, with lexical access progressing from left to right and letter by letter, but other models of visual word recognition assume that the word orthography is holistically activated in a parallel and synchronic way. Based on the latter perspective, the W&P and PDP models have gained advantage in their architectures because they see the sign as a complete activation with feedback information for representing concepts. This kind of disagreement and different perspectives arise because spoken language is a natural faculty and written language a recent adaptation of the visual system.

Friederici (2002) presents a detailed model of auditory recognition with the EEG time-course and fMRI space resolutions. Acoustic information arrives in the primary auditory cortex in the first 50 ms; then, phonemes are identified in Brodmann area (BA) 42 (STG: superior temporal gyrus) and phonologically segmented in BA44 (IFG: inferior frontal gyrus), followed by word-form identification until 150 ms. Between 150 and 300 ms, the word category is identified through syntactic structure processing in which the lemma and morphological information are activated in the posterior medial temporal gyrus (pMTG); then, between 300 and 500 ms, the semantic and morphosyntactic access occurs in posterior regions of the IFG (i.e., BA47 and 45 for semantics and BA44 and 45 for morphosyntactic processing); later, there are reanalysis and repair processes at approximately 600 ms in the IFG and frontal to parietal regions, as shown in Figure 8.

Figure 8 - The boxes represent the functional processes, the ellipses the underlying neural correlate. ELAN: early left anterior negativity, MTL: middle temporal lobe (Friederici, 2002).

It becomes clear from this model that the interests in the present thesis are the neurocognitive processes that take place during 150-500 ms, as well as which of these processes are reflected in the behavioral results. These processes are the identification of word category, probably the first morphological process to classify the word into a specific grammatical category (e.g., *parl[ez]<sub>ver</sub>/parl[é]<sub>adj</sub>/parl[eur]<sub>nom</sub>* ‘you<sub>pl</sub>

‘speak<sub>verb</sub>/spoken<sub>adj</sub>/speaker<sub>noun</sub>’); then, the lemma and morphological information are identified, i.e., after segmentation, the lemma is retrieved and activates its semantic features, providing the general meaning of the word, and the suffixes are activated, providing the morphosyntactic features of the word; finally, the word is integrated into the syntactic structure and clause phrase. We note that the last process, reanalysis and repair, seems important in morphological processing for the verification of word formation (Lavric et al., 2012; Schreuder & Baayen, 1995; Stockall et al., 2004).

Recently, Berwick et al. (2013) presented a detailed model of language processing, in which acoustic input is bilaterally processed by the STG, and information is distributed to the MTG and pSTG, with the latter being left-dominant and connected to the premotor cortex (PMC) and BA44 by different fiber pathways in the dorsal stream. The left-dominant STG is connected to BA45 and the anterior STG to BA47 by the ventral streams, as shown in Figure 9. This model is consistent with the dual-stream model of language processing (Hickok & Poeppel, 2004, 2007), and it also presents many similarities with the MUC (Memory, Unification, Control) model, in which, broadly, memory is retrieved from the temporal cortex, including the angular gyrus, unification is in the IFG (BA44 and 45), and control is in other portions of the frontal lobe (Hagoort, 2013). We note that these models are in line and share many similarities with the classic Wernicke-Lichtheim-Geschwind model of language (Geschwind, 1974).

Figure 9 - Language-related regions and fiber connections in the human brain. TC: temporal cortex, STC: superior temporal cortex (Berwick et al., 2013).

## 2.3 Morphological Processing

“The grammar must record the significance of morpheme order, whether this means significance for the meaning of the word or significance for the well-formedness of the word itself” (Spencer, 1991 p.74)

“Saussure even adopted the Greek terms ‘signifier’ and ‘signified’. Badouin then combined the Greek concept of the sign with the newly discovered sublexical units to reorient the definition of the sign from the word as a whole to its sublexical elements. Badouin placed roots, affixes, and inflectional endings into a single natural class, which he called, for the first time, ‘morpheme’. He originally defined his new concept as ‘the simplest psycho-linguistic element in the guise of sound’ (Badouin de Courtenay, 1889). But in Badouin de Courtenay (1895), he refined his definition to ‘that part of the word which is endowed with psychological autonomy and for that reason is not further divisible’” (Beard, 1995, p.5).

The debate about the nature of the word representations in the mental lexicon follows from discussions based on the architecture of language adopted: while the IP architecture supports the computational processing of abstract representations in the mental lexicon for word formation and recognition, the W&P architecture posits associations and relations between words in the organization of paradigms in the mental lexicon (Blevins, 2013; Hockett, 1954). Anderson (1992) proposed the W&P Extended framework, in which derived words are stored in the mental lexicon as whole forms with morphosyntactic representations, however inflection allows minimal interactions with syntax, which provides access to the word level but cannot define word formation.

Early psycholinguistic models of word recognition, such as the Logogen Model (Morton, 1969), the Whole Word (WW) model (Manelis & Tharp, 1977), and the Parallel Dual-Processing (PDP) models (McClelland & Rumelhart, 1981), do not consider the morphological processing. Additionally, the fields of psycholinguistics, neurolinguistics, and linguistics have developed substantially during the last 30 years, especially with experimental exploration in EEG, fMRI, magnetoencephalography (MEG), positron emission tomography (PET), computational linguistics, database development, simulations, and animal research. This theoretical and empirical knowledge must be incorporated into contemporary models of lexical access and word recognition, mental lexicon representations, and morphological and

language processing (Marantz, 2016). As introduced above, these advancements and findings simplified the theoretical linguistic descriptive and explanatory adequacies, giving rise to psycholinguistic hypotheses and the development of the biolinguistic program (Berwick & Chomsky, 2011; Boeckx et al., 2014; Chomsky, 2007).

Much discussion in psycholinguistics on the processing of morphologically complex words has focused on the following two questions: 1) What is stored in the mental lexicon? 2) To what extent is decomposition involved in word recognition? The answers have come in three flavors: a) All forms are listed in the mental lexicon as whole words without structure and morphological representation or connections to morphologically related words. b) All forms are listed in the mental lexicon with some representation of structure or connection, or both, for morphologically related words. c) Only morphemes are represented in the mental lexicon (Hankamer, 1992).

Moreover, for morphological processing in the visual modality, the string of graphemes does not define how many morphemes there are in the word and which segments should be assigned to which morpheme, but define the word boundaries; additionally, the parser requires a morphotactic component that specifies which combinations of morphemes are allowed. Morphological decompositional models can also be divided into affix-stripping models and root-driven models; for suffixing languages, this equates to right-to-left versus left-to-right algorithms. Both approaches have been taken from very early on in the history of morphological parsing (Forster, 1992).

## 2.4 Single-Route Models

“The way to understand language psychologically, it seems, is to see it as the most complicated example of such a secondary or referential set of symbols that society has evolved” (Sapir, 1929, p.212)

Hockett (1954) presented two models of grammar description, the Item-and-Arrangement (IA) and IP models, and finished his paper with an interest in the innovations of the Generative Grammar. Further, Halle (1973) published the prolegomena for the morphological research in the Generative Grammar framework. In this model, the mental lexicon is generative, and words are formed by systematic rules for morphemic combinations that are stored as whole words in a dictionary, as shown in Figure 10. The response to these models came soon, with Jackendoff (1975)’s Full-Entry Hypothesis, where words are stored in the mental lexicon as whole forms and have their morphological representations activated post-lexically.

Figure 10 – Halle (1973)’s morphological processing model.

Soon, psycholinguistic research started to provide evidence in favor of decompositional models with serial searching and symbolic manipulation (Taft & Forster, 1975; Taft, 1979), as well as of full-entry storage models (Butterworth, 1983; Manelis & Tharp, 1977). Stanners,



Neiser, Herson, and Hall (1979) found evidence in favor of the Split Hypothesis, in which morphological derivation is the construction of new words in the mental lexicon, whereas inflection is the composition of words with variables.

### 2.4.1 Obligatory Decomposition Model

Taft and Forster (1975) proposed the Obligatory Decomposition (OD) model for word recognition based on prefix-stripping experiments containing prefixed and pseudo-prefixed words (e.g., rejuvenate and repertoire, respectively), and manipulations between high and low surface and base frequencies. They propose that prefixed words are analyzed by means of their morphological constituents before lexical access; thus, decomposition is pre-lexical. They showed that nonwords that are stems from prefixed words (e.g., juvenate) are recognized more slowly than nonwords that are not stems (e.g., pertoire), as also that words that can appear as free or bound morphemes (e.g., vent) take longer to be recognized when the bound morpheme is more frequent than the free form. They proposed a morphological decompositional model with a search mechanism, as shown in Figure 11.

Figure 11 – Morphological decompositional model with prefix stripping and search mechanisms (Taft & Forster, 1975).

This model was developed further, with particular exploration of surface and base frequencies. The surface frequency is the frequency of the word occurrence in a corpus; generally, word frequencies are presented per million words. For example, if the word ‘play’ occurs 30 times in a corpus of 2 million words, its frequency per million is 15. In contrast, the base frequency, also known as cumulative frequency or stem frequency, is the sum of the surface frequency of all words that share the same base (e.g., play 15, plays 10, playing 5, played 1; base frequency 31) (Taft, 2004). Taft (1979) showed evidence that in pairs of words that share the same surface frequency, the word with higher base frequency is recognized more quickly than the word with lower base frequency.

The authors argue that for the pre-lexical decomposition trigger, prefixes would have to be represented in the peripheral sensorial system, whereas stems would be represented and accessed in the central system (Taft, 1991). The OB model is defined in three phases: first, words are decomposed based on morphological representations; second, the morphemic representations are searched and activated in the mental lexicon, yielding the base frequency effect; and third, morphemes are recombined, and the word is verified, yielding the surface frequency effect. Thus, the surface frequency is not interpreted as a difference in frequencies between whole forms but as the frequency at which the specific morphemes are combined to form a specific word (Colé, Segui, & Taft, 1997; Taft & Forster, 1975).

## 2.4.2 Whole Word Model

Jackendoff (1975)’s Full-Entry Hypothesis also departs from Chomsky (1970)’s “Remarks on nominalizations” problem of redundancy in the description of rules that allow partial overlap and idiosyncrasies in the mental lexicon relations. The author adopts the Lexicalist Hypothesis and proposes parallel representations of phonology, syntax, and semantics. Thus, lexical entries are fully stored and activate in parallel their different representations from the relations in the mental lexicon, as shown in Figure 12A. This kind of lexical access with later morphological processing characterizes post-lexical models. Manelis and Tharp (1977) adopt the more radical position that affixed words are recognized via their single units based on non-significant differences between affixed and non-affixed words. Butterworth (1983) provided evidence that a lexicon composed of whole words would be more economical in terms of processing resources than a lexicon with morphemic units and relations or rules computed every time a word is processed.

The parallel representation model evolved into the Tripartite Parallel architecture, which became a serious alternative framework to the UG (Jackendoff, 1997). The whole grammar has a triple representation: phonological, syntactic, and conceptual. Each level of representation has its own formation rules that define their structures; further, the parallel representations are connected by interfaces that apply the rules of correspondence, as shown in Figure 12B.

Figure 12 – A) The Parallel Representation and B) the Tripartite Representation models (Jackendoff, 1975, 1997).

Recently, the Constructional Morphology (CM) adopted the Tripartite Representation architecture and extended the types of representations stored as whole units (Booij, 2010a). The concept of schemas is strongly assumed for the phonological and syntactic levels, where not only words but also composed words, chunks, idioms, and sentences can be stored as whole units in the lexicon with their respective parallel representations (Booij, 2010b). In fact, the author adopts a position that there is no constraint on having whole units stored in the lexicon since they contain their parallel representations for language processing and interpretation.

### 2.4.3 Single Route Model

The Single Route (SR) model considers the DM framework for the linguistic analyses and behavioral predictions. Below, we briefly review the main concepts of DM and then move to the SR results. Three main characteristics specify the DM and distinguish it from other morphological theories and models. First, DM entails syntax all the way down, which means that syntactic processing keeps going within the word form; second, morphemes are underspecified, which means that they do not have to present all their relevant

morphosyntactic features but can be underspecified in default and general features; third, DM includes phonological late insertion, which means that the spell-out operation is delayed, and the phonetic form is constructed after syntactic/morphological processing (Harley & Noyer, 1999; Siddiqi, 2010).

A unique characteristic of DM is that it distributed the mental lexicon into three lists: List 1: Morphosyntactic Features, List 2: Vocabulary Items, and List 3: Encyclopedia. List 1 presents only abstract features that are activated by the vocabulary items from List 2, and List 3 presents the encyclopedia with the general knowledge about the world linked to the words (Embick & Noyer, 2007). Figure 13 presents a schema of the model incorporated in the recent SMT framework in (3) and that considers psycho- and neuro-linguistic processing in a serial order (Boeckx et al., 2014).

Figure 13 - The model of grammar in DM (Boeckx et al., 2014; Noyer, 2006).

In language production, the C-I level activates the syntactic structure and then the morphosyntactic features in List 1; the phonological exponent of a vocabulary item from the List 2 is inserted into a morpheme node. Vocabulary insertion is governed by two principles: 1) the vocabulary item in the competition that has the most features in common with the target

node without having any more feature will win the competition and be inserted, and 2) the target node may have more features than the vocabulary item to be inserted, but the vocabulary item may not have more features than the target node (Siddiqi, 2009).

When a vocabulary item is inserted, all functional features are erased from the derivation. Insertion is assumed to occur in phases, allowing an affix to see a stem after each phase (Marantz, 2007). These relationships to neighborhood morphemes allow a secondary vocabulary item to realize a feature from another vocabulary item. The Elsewhere Condition or ‘default’ allows the use of the exponent of a morphological pattern with the fewest requirements (Arregi & Nevins, 2013). In each phase of the linguistic derivation, the encyclopedia of general-domain knowledge in List 3 enriches the linguistic representations and feeds the conceptual meaning.

Moving to the psycholinguistic results, the SR model proposes that all complex words are processed by the universal grammar, from lexical roots and functional morphemes (Stockall & Marantz, 2006). The authors presented MEG evidence that regular and irregular English verbs are processed equally prior to lexical decision; they applied two priming experiments in which regular stems were primed equally to regular stems (e.g., play/played, give/gave) in the M350, which, as with the ERP N400, is a marker of the lexical access and semantic activation and integration (Lau, Phillips, & Poeppel, 2008).

In a previous work, Stockall et al. (2004) showed effects of frequency, probability, and density in a lexical decision task. The early MEG component M170 is associated with letter level processing and is affected by phonotactic probability, and the M350 sensitivity effect on lexical frequency was replicated from Embick et al. (2001). Further, they found lexical and sub-lexical effects in the M250 and M350; they reported that frequency and probability, but not density, affect the latencies of the M250 and M350. Recently, Fruchter, Stockall, and Marantz (2013) presented MEG evidence in a masked priming task for form-based decomposition of irregular verbs in English. They showed that the activity in specific regions of interest (ROI), the fusiform and inferior temporal regions, is modulated by the masked priming manipulation in the M170. Finally, Fruchter and Marantz (2015) showed evidence for the “decomposition, lookup, and recombination” processes, supporting the OD model, and proposed a full decomposition model of complex word recognition. They demonstrated an effect of morphological entropy, corresponding to the stem lookup phase, followed by a surface frequency effect, corresponding to the later recombination phase. Another study using a single-trial lexical decision task also showed that the M170 is modulated by morphological

complexity (Zweig & Pylkkaenen, 2009), supporting the idea that morphology is processed since early phases of the lexical access.

In summary, early MEG activity between 150 and 200 ms in the left hemisphere (M170) is associated with letter-string processing and activity between 300 and 400 ms (M350) with lexical activation. The functional significance of the activity in the 200–300 ms (M250) and 400–500 ms time-windows is less clear. The authors suggest that phonological factors, such as the frequency of the sounds in the word, affect the M250 (Morris & Stockall, 2012) and that activity between 400 and 500 ms is sensitive to the magnitude of lexical competition. The ERP N400, which is sensitive to both lexical and post-lexical stimulus factors (Friederici, 2004; Kutas & Federmeier, 2000; Lau et al., 2008), might be a summation of the MEG M250 and M350 activity; the activity after 500 ms reflects motor activity for the lexical decision response, as shown in Figure 14 (Pylkkänen & Marantz, 2003).

Figure 14 - Averaged MEG response of one participant to 69 visual words with a 93-channel axial gradiometer whole-head system (Pylkkänen & Marantz, 2003).

## 2.5 Connectionist Models

“We have adopted the approach of formulating the model in terms similar to the way in which such a process might actually be carried out in a neural or neural-like system” (McClelland & Rumelhart, 1981, p.387)

PDP models are also known as Connectionist models because they are networks of connections between units with different strengths in different levels of representations. With the development of computational neuroscience, modeling, and simulations, PDP models found a perfect environment for the proposition of an alternative kind of interactive-activation models (McClelland & Rumelhart, 1981; Rumelhart & McClelland, 1982). They represent language knowledge through interactive activation between the different levels of representations, as shown in Figure 15. “While the UG sees the human cognitive mechanisms as a symbolic, modular, innate and domain specific system, the connectionist framework sees the cognitive processes as graded, probabilistic, interactive context-sensitive and domain general” (McClelland & Patterson, 2002, p.465).

Figure 15 - McClelland and Rumelhart (1981)'s Parallel Dual Processing architecture. A) Orthographic features, letter, and word levels. B) Complete model. Arrows mean excitatory connections and balls mean inhibitory connections.

### 2.5.1 Parallel Dual Processing Models

According to Seidenberg (1992), grammatical theories are seen as abstraction about the behavior of the networks that determine performance, but the networks are not implementations of grammars: the networks behave in ways that cannot be deduced from the grammars. Essentially, PDP models are networks of units from different levels, and these networks compute the strength of their activations in hidden units. In general, they are trained using a sub-corpus, and then some effect is simulated from another similar corpus; then, the results are analyzed as a function of the predictions for the model and in comparison with empirical studies (Rumelhart & McClelland, 1982). Rumelhart and McClelland (1986) showed that a single-mechanism PDP model could handle the complete English verbal system of regular and irregular verbs without considering any morphological level or sublexical representation. Different models for visual and auditory recognition and production were developed according to the phenomena researched (Seidenberg, 2006; Seidenberg, 2007).

Devlin et al. (2004) showed fMRI evidence that morphology is the by-product of the overlap between form and meaning, it means, between phonological/orthographic representations and semantics. All three priming conditions produced overlapping effects in a bilateral region of the posterior angular gyrus; the left posterior occipital temporal cortex showed an effect of morphological relatedness overlapping with orthographic relatedness, and the left MTG showed overlap between the morphological and semantic relatedness effects, as shown in Figure 16.



Figure 16 - Bar plots show the mean percent BOLD for each condition in the ROIs. Effect sizes indicate reductions in activation from the unrelated word pair (Devlin et al., 2004).

PDP models have been established as orthographic processing models and go deeper into the interactive activations between orthography, phonology, and semantics in the hidden units controlled by excitatory and inhibitory processes. Carreiras et al. (2014) recently presented a developed model of word recognition, as shown in Figure 17. Interestingly, one can say that until the third block 'Hidden' from bottom to top in Figure 17A, the processes between baboons and humans are the same, and what differentiates human language understanding is the semantic access. It has been argued that the semantic access depends on the anterior and middle temporal lobe as well as on Broca's area (Caramazza & Hillis, 1991; Damasio, Grabowski, Tranel, Hichwa, & Damasio, 1996; Shapiro & Caramazza, 2003).

We can see that while the semantic blue areas are far from the orthographic red area, they are closer to the phonological brown areas, which support some kind of semantic dependence on the phonological activation. In a way, the hidden units <O-S> and <P-S> are the weighted units that are supposed to form the interface from phonology/orthography to semantics, and they might be involved in the syntactic and morphological processing during language processing.

Figure 17 - Recent connectionist models use large pools of excitatory neurons (-) and small pools of inhibitory neurons, weak distal connections (thin arrows) and strong local connections (thick arrows), and emergent hidden representations (<>). A) Structure generates B) simulated ERP components that explain empirical ERP data from C) middle parietal electrode. D) Comprehensive model with phonological, orthographic, and semantic representations (<o-p>, <o-s>, and <p-s>). E) IF: inferior frontal cortex, SG: supramarginal gyrus, AT: anterior temporal cortex, and OC: occipital cortex (Carreiras et al., 2014).

### 2.5.2 Naïve Discriminative Learning Model

The Naïve Discriminative Learning (NDL) model is also a recent word-recognition probabilistic model, but present many singularities in comparison to the other models (Baayen et al., 2011). The NDL model incorporates many different insights from information and computational processing theories as well as probabilistic equations of general learning and behavior (Norris, 2006; Rescorla & Wagner, 1972). In fact, the NDL is a form-to-semantics

activation model non-interactive, as shown in Figure 18. It does not consider a morphological level for word processing, and according to the author, it is in line with the architecture of the A-Morphous Morphology (Anderson, 1982, 1992). The NDL strongly considers the informational transmission theory assumptions, especially the concepts of word entropy (Kostić, 1991) and relative entropy between stems and suffixes (Moscoso del Prado Martín, Kostić, & Baayen, 2004). Therefore, it seems curious to consider a model without the morphological level in line with the A-Morphous Morphology and explores the relative entropy, which is a coefficient calculated from the morphological frequency of stem and inflectional suffixes for understanding the entropy of the relative frequencies in specific combinations. The A-Morphous Morphology actually strongly explores the morphological level to explain word formation; however, it states that morphology is not localized in a single component of language but is the result of many grammatical interactions, displacing morphemes but strongly positing rule-driven relations and complex morphosyntactic representations (Anderson, 1992).

The NDL is based on the equation of Rescorla-Wagner, which is a model for classic animal conditioning in Pavlovian assumptions, in which the animal learns from the discrepancy between what is expected to happen and what really happens (Rescorla & Wagner, 1972). Thus, they simulated the reading of the inflection paradigm effects without a morphological representation; surface frequency effects without a whole-word representation; family size effects in derived and composed words without postulating representations as such; and morpho-orthographic segmentation effects without postulating these mechanisms. According to the authors, “the success of the naive discriminative reader raises the question of whether other models might be equally successful. In what follows, we therefore compare the naive discriminative reader in some detail with the Bayesian reader of Norris (2006)” (Baayen et al., 2011, p. 472); therefore, they implemented a simple Bayesian reader and showed that the NDL still performed better than any other model.

Figure 18 – The Naïve Discriminative Learning model (Baayen et al., 2011).

It seems that in exploring the probabilistic and mathematical machinery of behavioral conditioning, the authors found an equilibrated solution for simulating many different reading effects known in the literature and for the development of a connectionist model with many fewer parameters than other PDP models; this model can handle the idiosyncrasies and singularities of human language without considering the morphological level of processing. Nevertheless, nothing is said about the true plausibility of these models in terms of psychological reality. It appears that linguistics and psychologists lost the idea of the complexity of mental calculus and probability when postulating these types of models; further, the adequacy of the neurocognitive explanation was neither empirically tested nor predicted from the available literature; thus, very little is known about how these kinds of models could work and be implemented in the human brain.

Therefore, it seems that connectionist networks are not always analogous to brain mechanisms; instead, they mostly incorporate pattern associations towards their standard training stimuli, giving their power for predicting irregular behavior of words. PDP models can probably simulate any linguistic phenomena, or even any cognitive phenomena, when the parameters are adjusted correctly and when they receive a good training phase (Pinker & Prince, 1988). However, it seems dangerous to reduce connectionism to a universal statistical approximation technique rather than a source of empirical predictions. Language cannot be treated as simply a collection of regularities in the input that can be approximated by some mechanism (Pinker & Ullman, 2002a).

## 2.6 Dual-Route Models

“When forms are partially similar, there may be a question as to which one we had better take as the underlying form... the structure of the language may decide this question for us, since, taking it one way, we get an unduly complicated description, and taking it the other way, a relatively simple one” (Bloomfield, 1933, p.218)

Bloomfield (1933) was certainly one of the first linguists to establish the idea that regular words are processed through productive rules, whereas irregular rules should be stored as exceptions in the mental lexicon. However, this distinction could certainly be mapped previously, where differences in the recognition of words and nonwords and of regular and irregular words were already discussed by Cattell (1886). Stanners et al. (1979) provided psycholinguistic evidence for the dichotomy of the processing of derived and inflected words (Badecker & Caramazza, 1989). Double-mechanism models explore both kinds of word access, procedural-combinatorial and declarative-associative, to explain the differences in word recognition between regular and irregular words, high- and low-frequency words, and root-, stem-, and word-based processing (Clahsen, 2006a).

### 2.6.1 Augmented Addressed Morphology

The Augmented Addressed Morphology (AAM) model was one of the first double-mechanism models to be proposed and its predictions remain pertinent. Burani, Salmaso, and Caramazza (1984) showed in three experiments that the frequency of the root morpheme, but also the surface frequency, of Italian inflected verbs determines latencies in lexical decision tasks. The authors found effects of both types of frequency and proposed that words may be represented in decomposed morphemes but that they can also be accessed by the address procedure in a whole-word system.

Later, Caramazza, Laudanna, and Romani (1988) applied three experiments exploring pseudoword structures of Italian inflected verbs to refine the model. The authors compared their results to the predictions of the WW and OB models; they found that nonwords are recognized significantly faster than pseudowords containing only the stem or only the

inflectional suffix and that words containing both morphemes but with illegal combinations present significant longer latencies than the other types. They proposed a whole-word route for known words, especially for those with high surface frequency, no semantic transparency, and irregular formation, and another morphological decompositional route for unknown words and for words with low surface frequency and high semantic transparency and predictable formation.

The AAM model showed through morphological manipulations that words might not be pre-lexically decomposed because nonwords are rejected more quickly than pseudowords; thus, it seems that nonwords are rejected pre-lexically because they have no means to have any kind of morphological access and that pseudowords have delayed responses because they engage mechanisms for word processing.

Evidence in the differences of the processing of derived and inflected words supports this model, in which regular inflection would be processed by the morphological decompositional route, whereas derivation and non-predictable words would be processed by the whole-word route (Badecker & Caramazza, 1989). Certainly, the morphological decompositional route can always explain the recognition of low-frequency words, as well as new and unknown words. Later work in the dissociation between derivation and inflection also supports this model in a more dynamic way, wherein different neural circuits are responsible for each kind of computation based on the predictability and productivity of the morphological processes (Bozic & Marslen-Wilson, 2010). Domínguez, Cuetos, and Segui (2000) review the morphological processing of Spanish words and their results in derivation and verbal and nominal inflection provide evidence in line with the AAM model. Regular verbs from the 1st class and regular nouns with feminine and plural inflection are based in the rule-based route, while verbs from the 2nd/3rd classes and irregular nouns are processed by the whole-word route.

This model, as well as the Parallel Dual-Route (PDR) model presented below, predicts an obvious role of the executive control in the inhibition of inexistent morphemes and illegal combinations of morphemes: the larger the inhibition, the larger the RTs. The AAM model opens the discussion about the levels of processing for lexical access and word recognition. The Two-Level (TL) model presented below explores lexeme and lemma levels for word activation. Beyond these levels, Caramazza (1997) complements this discussion with possible levels of processing for syntactic contextual information, conceptual representations, and semantic features, among others.

## 2.6.2 Parallel Dual-Route Model

Baayen, Dijkstra, and Schreuder (1997) formalized the Parallel Dual-Route (PDR) model as a mathematical probabilistic model. Both routes, the combinatorial and associative, are activated in parallel, and the faster one wins the race for lexical activation. According to the authors, the whole-word route seems to almost always win the race (Schreuder & Baayen, 1997). However, the PDR became an almost unfalsifiable model with its probabilistic inferential machinery based on many lexical factors; the PDR seems to always make good behavioral predictions about word latencies. Meanwhile, it has become a general dual-route model that can explain the most available results.

Importantly, psycholinguistic research and computational linguistic simulations showed that the family-size effect is a post-lexical effect. The family-size effect is a difference in RT regarding the size of a word family; it references the number of words that can be associated based on their form and meaning. It arises at a post-lexical phase of processing due to the semantic activation spreading along shared morphological representations (Jong, Schreuder, & Baayen, 2003). Additionally, the PDR model attributes a strong role for executive control processes to the inhibition of related forms and illegal combinations, slowing the combinatorial route; thus, the authors argue that homonym morphemes can influence the processing time of a word, demanding larger resources for morphological inhibition (Baayen & Schreuder, 1999).

## 2.6.3 Words and Rules and Declarative/Procedural Models

The Words and Rules (W&R) model predicts that regular words are recognized by symbolic manipulation and irregular words by associative activations (Pinker, 1999), following Bloomfield's idea that word recognition is performed via an initial search of the irregular exceptions in the mental lexicon, and if no item is found, the regular rule-based process is applied (Pinker, 1991).

This model received neurolinguistic support from the Declarative/Procedural (D/P) model, in which irregular and high-frequency words are recognized by the declarative route, and regular and low-frequency words are recognized by the procedural route (Ullman, 2001b). The procedural route is associated with grammar, and the procedural memory involves sequences, being subserved by the basal ganglia and frontal cortex, in the case of language. The declarative route is associated with the lexical, episodic, and semantic

memories, involving medial temporal and hippocampal areas (Ullman, 2001a). Therefore, when a word must be inflected, the lexicon and grammar are accessed in parallel; if an inflected form exists in the declarative memory, it will be retrieved, and a signal inhibits the procedural route. If no inflected form is found, the grammatical parser combines the morphemes for word formation between the stem and suffixes. The authors also present double dissociations between agrammatic and anomic patients, as shown in Figure 19 (Pinker & Ullman, 2002b)

Pinker (1997) showed a double dissociation for the grammatical and lexical processing in different areas of the brains. Aphasic patients who had temporal strokes presented deficits in the processing of irregular words, whereas patients with Broca's aphasia showed grammatical deficits in the processing of regular words, especially inflected ones. Later, further evidence for the W&R and DP models was accumulated from derivation, inflection, normal and aphasic participants, frequency, priming, L1 and L2, production, reading, EEG, and fMRI (Ullman, 2001c, 2007; Ullman et al., 2005).

Figure 19 – The Words and Rules and Declarative/Procedural models. A) Words/Declarative and Rules/Procedural mechanisms for word processing. B) Double dissociation in aphasic compared to control results (Pinker & Ullman, 2002b).



## 2.6.4 Minimalist Morphology

The Minimalist Morphology (MM) was proposed in an alternative framework from the MP (Wunderlich & Fabri, 1995). The MM considers that words are interrelated based on their inflectional (and derivational) paradigms, characterized by whole-word storage with post-lexical morphological processing and early lexical insertion in the syntactic structure. The early lexical insertion, contrary to the late insertion from the DM, presumes that words have their phonological representations stored as whole units in the mental lexicon, as shown in Figure 20.

The MM assumes a full decompositional root-based route for regular and productive morphological processes, as well as a sub-lexical partial decompositional stem-based route with hierarchical representations for irregular words and unproductive processes; alternatively, it can be considered that the MM also contains a third, purely associative, route with suppletion for idiosyncratic forms, where the same set of features is realized by different phonological forms in different environments, such as the verb ‘to be’ in English or *être*, *avoir*, and *aller* ‘to be, to have, and to go’ in French (Wunderlich, 1996). Fabri et al. (1995) applied a computational modeling and simulation of the morphological processing of German words based in the MM. It has been shown that the MM can explicitly generate all and only the correct inflected forms of both regular and irregular verbs. This study demonstrated the nontrivial potential of computer implementation for the testing of contemporary linguistic theories.

Psycholinguistic evidence has shown that the MM can hold a large part of the German and Dutch systems of inflection (Penke, 2006). Penke, Janssen, and Eisenbeiss (2004) showed that the predictions of this model allow the study of fine-grained levels of computation, for example, based on the underspecified hypothesis, in which inflectional suffixes have different morphosyntactic features to be processed, with that processing then affecting human behavior during word recognition and sentence processing.

Clahsen (1999) provided extensive evidence in German derivation and inflection in behavioral, EEG and fMRI experiments for a dual-mechanism model in line with the MM, with one single rule as the default full-decomposition rule-based system and other processes hierarchically structured with sub-lexical processing. The author argued that the results presented and the complex German inflectional system could not be modeled or simulated by PDP models and that symbolic-manipulation assumptions should be evaluated prior to the interpretation of the results. This study received substantial criticism from a psychological

realistic perspective regarding how the neurocognitive system would implement the kind of structure and rule-based application proposed. A study on Portuguese inflected verbs also provided evidence for this kind of model, in which regular verbs from the 1st class would be the single root-based class, and verbs from the 2nd/3rd classes and morphophonological verbs would have semi-structured representation with sub-lexical specifications (Veríssimo & Clahsen, 2009).

Morphological aphasias do not present any phonological violation, instead mostly the erasing or the change of a morpheme in the inflected words. This does not mean that aphasics lost the morphological constituents but instead that they cannot make the correct choice in the word formation and processing. Morphological aphasias present different manifestations between derivation and inflection and in languages of different typologies (Jarema & Libben, 2006). Neurolinguistic evidence showed that English and German aphasic patients are much more likely to perform tense morpheme suppression than agreement suppression. The feature-interpretation hypothesis stated that some kinds of aphasia affect the interpretation of specific morphosyntactic features (Clahsen & Ali, 2009; Wenzlaff & Clahsen, 2004). This kind of finding is consistent with the MM and DM regarding the feature-underspecification hypothesis for language interpretation.

Figure 20 – Minimalist Morphology model inheritance trees for sub-lexical route representations for the processing of strong German verbs.

## 2.6.5 Two Level Models

Here, we discuss models that were not developed using the architecture of two different routes for word recognition but which explored Two Levels (TL) of word processing. Aronoff (1976) presented a theory in which words are constructed from other words, meaning that each word is a potential stem for the formation of other words (e.g., *parle/parler/parlera/parlerai/parlerait* ‘I/he speak(s)/to speak/he will speak/I will speak/he would speak’). The author developed the derivational word formation rules, arguing that words are formed and stocked in the mental lexicon in line with the full-entry hypothesis; later, the inflectional paradigm was developed in a more stem-based architecture (Aronoff, 1994). Anderson (1982; 1992) developed the W&P Extended theory, considering that derivation is for the relations of words in the lexicon and that syntax can have access to the word formation rules and morphosyntactic representations in inflection.

The Lexeme-Morpheme Based Morphology (LMBM) clearly stated the differences between lexical morphemes and functional morphemes (Beard, 1995). Lexical morphemes are roots and stems, which activate the semantic features with the main word meaning, while functional morphemes are grammatical affixes, which activate the morphosyntactic features for word processing. These formulations are clear consequences of the Lexicalist Hypothesis, which states the separation between syntactic and lexical component, as well as of the Split Hypothesis, which considers a separation between derivation and inflection in the morphological component. They evolved in models with at least two levels of processing, lexeme and lemma or lexeme and morpheme.

Allen and Badecker (1999)’s results in two priming experiments on Spanish homographs found inhibitory effects in homographic stem primes compared to unrelated and orthographic controls; in a second experiment, they found the same effect using allomorphic stem primes and suggested a multi-level model with morphologically decomposed representations. In another study, they found that orthographically allomorphic stems in English verbs (e.g., *taught/teach*) show priming facilitation, suggesting a two-level lexicon in which allomorphic forms are represented as lexemes, which subsequently activate the lemma representation, as shown in Figure 21A (Allen & Badecker, 2002).

Figure 21 – A) Two Level model (Allen & Badecker, 2002). B) Morpho-Orthographic model (Crepaldi et al., 2010).

The essence of these approaches is that words are analyzed from left to right, and the primary objective is to recover the stem information; thus, this information can be separated from inflectional information, allowing the two types of information to undergo independent processing (Henderson, 1992). Rastle, Davis, and New (2004) adopted this line of research in the morpho-orthographic level of processing, especially exploring pseudo-morphological priming effects in masked priming experiments. They found that apparent morphological relationships between primes and targets (e.g., corner/corn) present large priming effects, but primes with non-morphological relationships with the targets (e.g., brothel/broth) do not facilitate responses, arguing that words are visually morpho-orthographically decomposed irrespective of whether the meaning is related to the stem. Later, the authors proposed that morphological decomposition is dependent on a purely orthographic analysis, where words are segmented simply because they have a morphological structure (Rastle & Davis, 2008).

These findings were extended in a study that found in three masked priming experiments that ‘fell’ does facilitate ‘fall’ more than orthographic ‘fill’ and control primes. This evidence could be explained by pure orthographic processing, and the authors suggest a second level of masked morphological priming at the lemma level, where inflected words but not derived words share their representation irrespective of orthographic regularity, as shown in Figure 21B (Crepaldi et al., 2010). The same kind of morphological priming effect without morphological relationship in masked priming experiments has been found in French, where there is no facilitation for orthographic overlap (e.g., *abricot/abri* ‘apricot/shelter’), but there are equivalent priming facilitation effects in morphologically related words (e.g., *gaufrette/gaufre* ‘wafer/waffle’) and pseudo-morphologically related words (e.g.,

*baguette/bague* ‘stick/ring’), providing evidence that words are early decomposed by means of their structures and morphological representations (Longtin & Meunier, 2005; Longtin, Segui, & Hallé, 2003).

Another kind of evidence for two levels of processing in inflected Spanish verbs comes from fMRI results that show a dissociation between the activations of the phonological processing of the lexical morphemes in regular and irregular words in the temporal areas, with morphosyntactic processing of the inflected suffixes in both types of verbs occurring in the IFG (de Diego Balaguer et al., 2006). Spanish, like other Romance languages, almost always presents inflectional suffixes independently of the regularity of the stem; the results showed that areas related to grammatical processing are active for both types of verbs (left opercular inferior frontal gyrus). The authors noted that areas of the prefrontal cortex were selectively active for irregular production, presumably reflecting the lexical retrieval (bilateral inferior frontal area and dorsolateral prefrontal cortex); however, regular verbs showed increased activation in areas related to grammatical processing (anterior superior temporal gyrus/insular cortex) and in the left hippocampus, possibly related to a greater involvement of the phonological loop necessary for the reutilization of the same stem for shared forms in regular verbs, as shown in Figure 22.

Along the same line of argument, Marslen-Wilson and Tyler (2007) argued for a core decompositional network linking the left inferior frontal cortex with the superior and middle temporal cortex, connected via the arcuate fasciculus. This handles the processing of regularly inflected words by morphophonological decomposition in order to segment complex words into stems and inflectional affixes. This parsing process operates early and automatically in all potential inflected forms, being triggered by their surface phonological properties (Fabre, Schoot, & Meunier, 2007).

Figure 22 – A) Comparisons between inflection and repetition tasks by verb condition. B) Comparison between irregular and regular inflection conditions. C) Comparisons between the nonce verb and real verb (regular and irregular) in the inflection task. Color scales refer to the t-value contrasts, N = 12.

## 2.7 French Verbal System

“L’écriture, qui semble devoir fixer la langue, est précisément ce qui l’altère; elle n’en change pas les mots, mais le génie ; elle substitue l’exatitute à l’expression. L’on rend ses sentiments quand on parle et ses idées quand on écrit” (Rousseau, 1993, p.73)

French is a Romance language inherited from Latin, from the Gallic family during the Middle Age; it is the official language in 29 countries and the fourth most spoken language as mother tongue in European Community, accounting more than 220 million speakers in the world. French verbs are formed by a lexical morpheme in the left side of the word containing the stem with the semantic features and meaning, and functional morphemes in the right side of the word expressed by inflectional suffixes with the morphosyntactic features for grammar processing (Embick & Halle, 2005; Kilani-Schoch & Dressler, 2005; Mross, 2013).

French is an interesting Romance language to be studied in psycholinguistics because: 1) French is the only language with an iambic prosodic system (Andreassen & Eychenne, 2013), 2) French has a large inconsistency in the relations between grapheme and phoneme (Ziegler, Jacobs, & Stone, 1996), and 3) French obligatory realizes the subject of the sentence, accordingly to the Extended Projection Principle (EPP) (Chomsky, 1993). One can consider that French is conservatory in keeping the old orthographic system, while the phonological/phonetic forms evolved in the last centuries, resulting in a large inconsistency between the orthographic and the phonological forms (Touratier, 1996). As a result, French have many homophones in the phonetic form which are clearly differentiated in the orthographic form (e.g., *parler/parlez/parlé(e)(s)* ↔ /,paR'le/ ‘to speak/you<sub>pl</sub> speak/spoken<sub>mas/fem, sg/pl</sub>’).

Additionally to these morphophonological factors, syntactically, “in English or French the object must move to a case-marked position, but in a language such as Spanish or Italian that permits the subject to be an empty category, this empty category can “transfer” its nominative case to the object so that the object need not appear in the position to which nominative case is assigned” (Chomsky, 1988, p.120). It means that French is also the only Romance language which the subject of the sentence has to be obligatorily realized, as English. Therefore, while other Romance languages can express the empty subject by the

pronunciation of the verbal inflectional suffixes, French realize overtly the subject and, as consequences, the syntactic information from the inflectional suffixes is lost in the phonological form (e.g., French *il parle-tu parles* ↔ /il'paRl/-ty'paRl/; Spanish: *habla-hablas* ↔ /a'bla/-a'blas/ 'he speaks/you<sub>sg</sub> speak'). Thus, it seems that independently of the historical orthographic persistence of the verbal inflectional suffixes markers, the obligatory realization of the subject preceding the verb allowed the erasure of these markers in the phonological forms, avoiding redundant morphological information. Nevertheless, we note that beside the redundant information in the subject pronoun and verbal agreement suffix, the 3rd singular and plural forms which do not start with vowels remains phonologically syncretic (e.g., *il parle-ils parlent* ↔ /il'paRl/ 'he speaks-they speak').

French present more than 8,000 verbs, with the largest part being fully regular verbs from the 1st class ending in [√er]. The 2nd class accounts approximately 250 verbs and is also fully regular (Bonami, Boyé, Giraud, & Voga, 2008) with ending in [√ir] and allomorphic forms in [√iss-] when the stem is merged with a vocalic inflectional suffix (i.e., [√i] ↔ [√iss-]/\_V). The 3rd class accounts approximately 350 verbs with different endings and present many micro-classes with stem allomorphs accordingly to phonological constraints (Kilani-Schoch & Dressler, 2005). French verbal system accounts two numbers: singular and plural; and three persons in each number: 1st, 2nd, and 3rd; resulting in a system with six agreements. Further, French have four moods and eight tenses. Indicative: present, simple past, imperfect past, and simple future; Conditional: present; Subjunctive: present, imperfect past; and Imperative: present. Additionally, French presents three nominal forms: present participle, past participle, and infinitive, as summarized in Figure 23 (Hachette, 2008). However the indicative simple past and subjunctive imperfect past tenses are nowadays obsolete tenses, being restricted to the literature and formal communication.

The French verbal inflection is a prototypical inflectional class in Romance languages, exploring sets of inflectional suffixes to express the morphosyntactic information and stems to express the word meaning. Thus, allomorphy are dynamic morphological processes to phonologically adjust the morphemes for morphological combinations accordingly to phonological constraints. The verb is the heart of the sentence, it is the verb that project, designate, and organize the clause arguments and their hierarchy of relations (Marantz, 2013b). Verbs can express actions, states, change of state, natural phenomena, occurrence, and other processes. A number of theories have focused on the representation of verbs and the structural implications of those representations for the language interpretation, linking the



syntactic subcategorization properties of verbs with their argument structure for the semantic interpretation (Tyler, 1992).

Figure 23 – Summary of the French verbal inflectional system (Hachette, 2008).

### 2.7.1 Structural Paradigm

Following the structural method of morphological commutation analyses, Estivalet and Margotti (2014) analyzed the inflectional suffixes system and paradigms from French verbs. This classification was adapted and clarified based on allomorphy, syncretism, and incorporation processes in the French verbal inflectional system (Spencer, 1991; Stump, 2001); Table 1 presents the tense morpheme paradigm and Table 2 presents the agreement morpheme paradigm.

Mood	Indicative				Conditional	Subjunctive		Imperative
Tense	Pres.	Simple Past	Imp. Past	Simple Fut.	Pres.	Pres.	Imp. Past	Pres.
1sg	∅	∅	ai	r	rai	e	ss	-
2sg	∅	∅	ai	r	rai	e	ss	∅
3sg	∅	∅	ai	r	rai	e	∅	-
1pl	∅	∅	i	r	ri	i	ssi	∅
2pl	∅	∅	i	r	ri	i	ssi	∅
3pl	∅	r	ai	r	rai	∅	ss	-

Table 1 – Tense inflectional suffixes by the different tenses and agreements (Estivalet & Margotti, 2014).

Mood	Indicative				Conditional	Subjunctive		Imperative
Tense	Pres.	Simple Past	Imp. Past	Simple Fut.	Pres.	Pres.	Imp. Past	Pres.
1sg	e/s/x	i/s	s	ai	s	∅	e	-
2sg	(e)s/x	s	s	as	s	s	es	∅/s
3sg	e/t/∅	∅/t	t	a	t	∅	t	-
1pl	ons	mes	ons	ons	ons	ons	ons	ons
2pl	ez	tes	ez	ez	ez	ez	ez	ez
3pl	ent	ent	ent	ont	ent	ent	ent	-

Table 2 – Agreement inflectional suffixes by the different tenses and agreements (Estivalet & Margotti, 2014).

These tables follow from the natural idea of concatenative morphology, where different morphemes are linearly concatenated accordingly to the morphotactics constituency of the language. In Romance languages, the inflectional suffixes of tense and agreement are considered cumulative morphemes, where the former is the temporal-mood inflectional suffix (TMS) and the latter the personal-number inflectional suffix (PNS) (Dubois, 1967; Margotti, 2008). Thus, French verbal inflection follows the general Romance language system defined

by a stem formed by the root and theme vowel, merged with the TMS and PNS: stem+TMS+PNS (Bescherelle, 2006; Touratier, 1996). We remark that the notion of verbal stem adopted in the present thesis overlap with the definition of theme, which is the combination between the root and the theme vowel (Aronoff, 2012; Bermúdez-Otero, 2013).

The zero morpheme is a null marker which indicates that there is no morpheme to express a specific category or cluster. It follows that the indicative present is the default tense and do not present any tense marker; also, the simple past does not present any tense morpheme, but in the 3rd person plural, however, the simple past morphosyntactic feature is expressed in its specific agreement morphemes, as shown in Table 2. The zero morpheme express the default categories which are not phonologically expressed, and is in line with the underspecified feature hypothesis and Elsewhere Principle (Arregi & Nevins, 2013; Penke et al., 2004), where default markers do not have to fully specify their features (Noyer, 2006). In French, we consider the follow default categories in verbal inflection: conjugation: 1st class, mood: indicative, tense: present, number: singular, and person: 3rd person (but the 2nd person seems to be the default in the plural).

Concerning the verbal stems and tense formations, the primitive tenses are the infinitive, the indicative present and simple past. The indicative imperfect past tense is formed by the stem from the indicative present tense in the 1st plural agreement (i.e., 1st class: *[parl]ons*, 2nd class: *[finiss]ons*, and 3rd class: *[buv]ons*) merged with the tense and agreement inflectional suffixes from the indicative imperfect past tense. The simple future tense is based in the infinitive form or, alternatively, in the stem from the indicative present tense in the 3rd singular agreement merged with the [-r-] future morpheme, and the *avoir* ‘to have’ auxiliary verb conjugated in the indicative present (e.g., 1st class: *[parler]*, 2nd class: *[finir]*, and 3rd class: *[boir]*) (Kilani-Schoch & Dressler, 2005). The conditional present tense is formed from the same stem of the indicative simple future tense, but the stem is merged with the tense and agreement inflectional suffixes from the indicative imperfect past tense. The subjunctive present tense is formed from the stem from the indicative present tense in the 3rd plural agreement (i.e., 1st class: *[parl]ent*, 2nd class: *[finiss]ent*, and 3rd class: *[boiv]ent*) merged with the 1st class agreement inflectional suffixes from the indicative present tense and the tense inflectional suffixes from the indicative imperfect past tense from the 1st and 2nd plural forms. The subjunctive imperfect past is formed from the stem from the indicative simple past tense in the 3rd singular agreement merged with the tense inflectional suffixes from the subjunctive imperfect past tense and the same agreement inflectional suffixes than the subjunctive present tense, but the 3rd singular forms, presenting [-t] ending (i.e., 1st class:

[*parl*]a, 2nd class: [*fini*]t, and 3rd class: [*bu*]t) (Dubois, 1967). Finally, the imperative is directly derived from the indicative present tense with a single deletion of the [-s] 2nd singular agreement morpheme in the 1st class (Estivalet & Margotti, 2014).

We note that the indicative simple future tense is clear examples of encoding of functional words as functional morphemes. The formation of the indicative present future verbal forms can be summarized as the infinitive form ending in [-r] combined with the conjugation of the auxiliary verb *avoir* ‘to have’. Thus, we can note the nature of the auxiliary verb with a grammatical function, which is realized as free morphemes, being attached to a stem to construct a more complex tense. Interestingly, although the auxiliary verb followed by the past participle makes the *passé composé* composed tense, the auxiliary verb after the infinitive form makes the indicative future tense (Bybee, 1985).

French prefixes are attached in the left side of the root to form complex stems. Prefixation is not an inflectional processes but a derivational one, since it does not change any morphosyntactic characteristic of the word, but adds lexical semantic features to the stem, thus, prefixation is a morphological derivation within the stem node (vP) in the verbal structure (Matthews, 1991; Spencer, 1991). We list below the most productive French prefixes with transparent lexical meaning when attached to a roots for stem formation; while some prefixes are bound forms, others are free forms: [abs-], [ad-], [con-], [de], [entre], [in-], [inter-], [intra-], [re-], [par], [per-], [pre-], [sou-], [sur], among others (Cole, Beauvillain, & Segui, 1989; Dubois, 1967; Tsapkini, Jarema, & Di Sciullo, 2004).

## 2.7.2 Morphography

Interestingly, pure morphophonological processes only occur in the French verbs from the 1st class. Additionally, only the 1st class has simple orthographic allomorphic processes in the stem formation for phonological adjustment which are highly predictable: a) [-cer] (e.g., *placer/plaçons* ‘to place/we place’), b) [-ger] (e.g., *manger/mangeons* ‘to eat/we eat’), c) [-yer] (e.g., *payer/paies* ‘to pay/you<sub>sg</sub> pay’). These orthographic allomorphic processes are motivated by morphographic characteristics (Taft, 1991), it is, they occur in graphemes which have more than one phonetic realization (i.e., <c> ↔ /s/ <e|i> | /k/ <a|o|u|C>, <g> ↔ /ʒ/ <e|i> | /g/ <a|o|u|C>, <y> ↔ /ej/ <a>\_ | /waj/ <o>\_).

In general, when French words are written in upper case, the orthographic accentuation is not marked, in contrast, words in lower case always present their orthographic accentuation

(e.g., *PREFERE*, *préféré-préfère* ‘preferred<sub>past.part.</sub>-I/he prefere(s)'). As a consequence, upper case orthography should reduce orthographic processing because of the lack of accents, but the prosodic surface is less informative, resulting in competition between forms; inversely, lower case orthography demand extra processing of the orthographic and prosodic accents, but avoids homographic and homophonic forms, reducing competition for recognition (Quémart, Casalis, & Duncan, 2012).

Consonants		Labial	Dental	Alveolar	Palatal	Velar	Uvular
Nasal		m	n		ɲ	ŋ	
Plosive	Voiceless	p	t	tʃ		k	
	Voiced	b	d	dʒ		g	
Fricative	Voiceless	f	s	ʃ		x	
	Voiced	v	z	ʒ			ʁ
Approximant	Plate		l		j		
	Rounded				ɥ	w	

Table 3 – French consonants and semi-vowels accordingly to the IPA.

Vowels		Front		Central	Back
		Unrounded	Rounded		
Close	Oral	i	y		u
Close-mid		e	ø	ə	o
Open-mid		ɛ	œ		ɔ
	Nasal	ɛ̃	œ̃		ɔ̃
Open					ɑ̃
	Oral				a

Table 4 – French vowels accordingly to the IPA.

Below, we briefly present the French specific graphemes, the vowels in Table 3 and the consonants in Table 4, accordingly to the International Phonetic Alphabet (IPA). Further, we

present and discuss the French diphthongs in Table 5. As specific graphemes, French have the <œ> ↔ /œ/, <æ> ↔ /ɛ/, <ç> ↔ /s/. The acute accent forces a close production of the vowel <é> ↔ /e/, while the grave accent forces an overt production <è> ↔ /ɛ/. The circumflex accent <â, ê, î, ô, û> forces the productions /ɑ, ɛ, i, o, y/ respectively, most often the circumflex accent indicates a diachronic erasure of the ‘s’ segment (e.g., *château* < *castel* ‘castle’, *fête* < *feste* ‘party’, *sûr* < *seur* ‘sure’, *diner* < *disner* ‘dinner’). Finally, the trema indicates that the vowel should be pronounced separately from the preceding segment, forcing an hiatus <ë, ï, ü, ÿ> ↔ /e, i, u, y/ respectively. Even if neglected in most psycho- and linguistic research, the processing and representation of orthographic accentuation in relation to the phonological form might be considered in morphological processing and word recognition.

Diphthongs		False Diphthongs	
Grapheme	Phoneme	Grapheme	Phoneme
<ei>	/ej/	<ai>	/ɛ/
<ail>	/aj/	<au/eau>	/o/
<ill>	/ij/	<oe>	/œ/
<ia>	/ja/	<eu>	/ø/
<ie>	/je/	<ou>	/u/
<ien>	/jẽ/	<an/am/en/em>	/ã/
<io>	/jo/	<in/im/un/um>	/ĩ/
<ion>	/jõ/	<on/om>	/õ/
<oi>	/wa/	<ch>	/ʃ/
<oin>	/wẽ/	<gn>	/ɲ/
<oui>	/wi/	<ph>	/f/
<ui>	/qi/	<sc_E/i>	/s/
<uin>	/qẽ/	<y>	/ii/

Table 5 – French diphthongs.

We considered simple diphthongs when the realization of two or more graphemes result in one phoneme combined with a semi-vowel, and false diphthongs when it result in a single phoneme. We remark that these singularities between phonological and orthographic forms in French may be processed for word recognition as grapheme-to-phoneme rules (Taft, 1991); while simple diphthongs should have a natural phonological processing with the shortening of one of the vowels (e.g., <ei> ↔ /ej/), false diphthongs imply a conversion of two graphemes in one phoneme (e.g., <ai> ↔ /ɛ/). Another interesting aspect is that French, like English, has words which the phonological form do not correspond to the phonological one (e.g., <yacht> ↔ /ja'tʃ/), where pronunciation rules do not follow the phonetic sound fixed for a letter or chain of letters. This characteristic has been argued to accentuate the cognitive troubles linked to the grapheme-phoneme relation in these languages, as dyslexia and agraphia (Dehaene & Cohen, 2011; Facchetti et al., 2003; Janiot & Casalis, 2012).

### 2.7.3 Morphophonology

In what concerns the French verbal stem formation, we can consider four basic processes in the interaction with the inflectional suffixes. Stems can be 1) fully regular (i.e., most part from 1st class stems, all 2nd class stems, and some 3<sup>rd</sup> class stems), can present 2) morphophonological processes (e.g., only 1st class stems, orthographic mark: *appeler-appelles* ↔ /,ape'le/-/a'pɛl/ 'to call-you<sub>sg</sub> call'; no orthographic mark: *adorer-adores* ↔ /,ado'Re/-/a'dɔR/ 'to adore-you<sub>sg</sub> adore'), can present 3) sub-regularities (e.g., *savoir-sait* ↔ /sa'vwɑR/-/'sɛ/ 'to know-he knows'), and can present 4) suppletion (e.g., *aller-va* ↔ /a'le/-/'va/ 'to go-he goes') (Meunier & Marslen-Wilson, 2004).

The orthographic marked forms received larger attention in reading studies, when the last 'e' vowel of the root is a stressed syllable, it receives an overt pronunciation /ɛ/ and an orthographic mark directly in the phoneme <è> or in the subsequent grapheme <ell|ett> (e.g., *peser-pèses* ↔ /pe'ze/-/'pez/ 'to weight/you<sub>sg</sub> weight', *jeter-jettes* ↔ /ʒe'te/-/'ʒɛt/ 'to throw/you<sub>sg</sub> throw, *appeler-appelles* ↔ /,ape'le/-/a'pɛl/ 'to call/you<sub>sg</sub> call; /e/ ↔ /ɛ/<sub>stress\_<ll|tt></sub>) (Chevrot, Brissaud, & Lefrançois, 2003); in contrast, the non-marked forms are much less studied (e.g., *adorer-adores* ↔ /,ado'Re/-/a'dɔR/ 'to adore/you<sub>sg</sub> adore; /o/ ↔ /ɔ/<sub>stress</sub>) (Estivalet & Meunier, 2015a).

As introduced above, the French verbal system has been morphologically simplified because of the obligatory realization of the sentence subject. Additionally, the personal 2nd plural *nous* 'we' pronoun has been substituted by the impersonal 3rd singular *on* 'we/one'

pronoun. It follows that only two inflected forms can hold the system in the indicative present and composed tenses of the 1st class verbs (i.e., *je parle-tu parles-il parle-on parle-ils parlent* ↔ /'paRl/ 'I speak-you<sub>sg</sub> speak-he speaks-we/one speak-they speak' and *vous parlez-parler-parlé* ↔ /paR'le/ 'you<sub>pl</sub> speak-to speak-spoken') (Kilani-Schoch & Dressler, 2005).

The verbs from the 2nd class completely incorporated the [√i] theme vowel in all their roots and establish the [√iss-] allomorphic stem which is merged with vocalic suffixes. Regarding the micro-classes from the 3rd class, Kilani-Schoch and Dressler (2005) present an exhaustive linguistic description with more than 25 meaningful micro-classes with specific processes for stem formation. These micro-classes are mainly characterized by their endings and the allomorphic rules for the stem readjustment form; the higher hierarchical nodes in the subdivisions of the micro-classes can be summarized in the following 3rd class main endings: [-er], [-ir], [-oir], [-ire], [-ure], [-cre], [-dre], [-pre], [-tre], [-vre], [-indre].

The Lexical Phonology divided the phonological component into two modules: lexical and post-lexical phonological processing. The rules applying in the lexical component are sensitive to word morphemic representations, and the post-lexical component only applies since morphological structure is no longer available, it means, in the whole word form, phonological phrase, and clause. Moreover, the post-lexical component can create segments that are not present in the underlying representations (Frauenfelder & Lahiri, 1992). Marslen-Wilson and Zhou (1999) showed that morphophonological forms may be stored as abstract underlined representations in the mental lexicon. Words compute their phonetic form based in the linguistic context of the phonemes and word boundaries. These finding is in agreement with the late phonological insertion and readjustment rules from the DM, where phonetic forms are only computed in a late spell-out, as also to the lexical and post-lexical processing in Lexical Phonology (Embick, 2013).

Another important aspect in French is that <e> ↔ /ə/ became a schwa when it is the last vowel of the word, not being pronounced but sometimes accentuating the precedent consonant pronunciation (e.g., *étudiant-étudiante* ↔ /,ety'djã-/ ,ety'djãt/ 'student<sub>mas</sub>-student<sub>fem</sub>'). Interestingly, this 'e' became the hypothetical theme vowel from the 1st class (Foley, 1979) and was incorporated as the default agreement morpheme for the singular forms in the indicative present tense of the 1st class, and in all classes in the subjunctive present tense. Additionally, all last consonants from the French verbal inflectional suffixes (i.e., <s> ~ <x>, <z>, and <t>) are not generally pronounced, but when there is the liaison with a subsequent word beginning by vowel or mute 'h' (Chevrot, Dugua, Harnois-Delpiano,

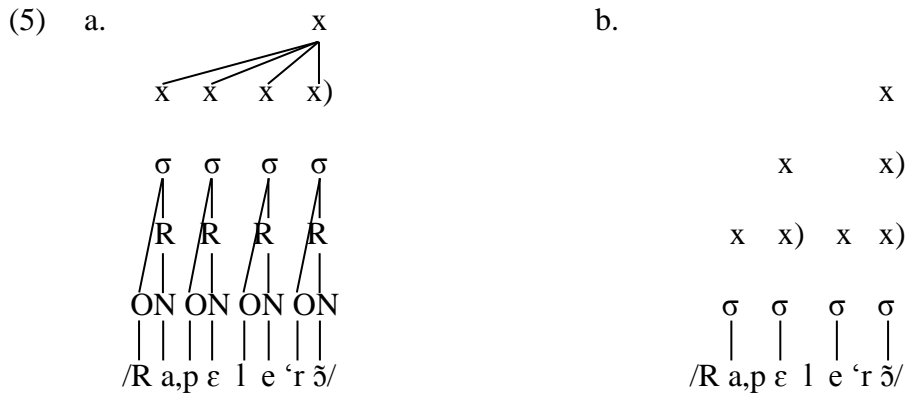


Siccardi, & Spinelli, 2013; Touratier, 1996). The result is that French lost the morphological information of the inflectional suffixes in the phonetic realizations, but kept this morphological information in the orthographic forms and grammatical underlined representations.

### 2.7.4 Prosody

A word has at least one pronounced syllable (e.g., *a* /'a/ 'he has', *parlent* /'parl/ 'they speak'), which equal to one prosodic feet, nevertheless, by perceptive and rhythmic reasons of contrast an optimal prosodic feet is binary, thus the ideal word has two syllables, two foot (Kilani-Schoch & Dressler, 2005). French has been traditionally classified as a final stress language where only the last pronounced syllable is stressed by duration, and the other syllables are plate, as shown in (5a). However, there are reasons to consider that French has also secondary stresses in the word level (5b), phonetic phrase, and clause (Andreassen & Eychenne, 2013; Estivalet & Brenner, 2012). While most Romance languages have a trochaic prosodic system with the stress falling in the ultimate, penultimate, or antepenultimate syllables, French has an iambic prosodic system with the stress always falling in the ultimate syllable, as also having secondary stresses in the phonological derivations.

French inflected verbal forms which do not have any inflectional suffix pronounced, because they are schwa and/or consonantal segments, have their main stress in the stem; and inflected verbal forms which have at least one inflectional suffix pronounced have their main stress in the inflectional suffixes; consequently, secondary stresses fall in the stem of the word in the latter case. Accordingly to Cutler (1992, p.354): "Where do we start lexical access? In the absence of any better information, we can start with any strong syllable", thus, lexical access starts as soon as possible from the first strong syllable, and should not has to wait for a single stress only in the final of the word. Metrical prosody is a simple system with only two levels, strong and weak foot; a strong syllable is any syllable containing a full vowel or diphthong or coda, while a weak syllable contains a reduced vowel (Goldsmith, 1990; Halle & Idsardi, 1996).



rappellerons ‘we will recal’

It was showed that changes in word metrical prosodic structure inhibit word recognition, while changes only in the lexical prosodic form do not. This is consistent with the view that lexical representations have no stress patterns, but only segmental representations with full and reduced vowels. The distinction between full and reduced vowel in the pre-lexical representation suggests an indirect role of prosody in the lexical access, consequently, metrical prosody plays a role in lexical access even if lexical prosody does not (Cutler & Clifton, 2000; Cutler, 1992). It follows that the prosodic form with the main and secondary accents interacts with the morphological structure (Oltra-Massuet & Arregi, 2005), thus, operations in the morphological level directly affects the word stress pattern, the lexical access and word recognition.

It becomes clear that words with more than two foot have secondary stresses by a simple analysis of the quality of the vowel in the antepenultimate pronounced syllable. For example, the verbal form *appelles* /a'pɛl/ ‘you<sub>sg</sub> call’ has two syllables and thus only a main stress in the last pronounced syllable of the stem, where the <e> has an overt pronunciation in the /'pɛl/ syllable (Chevrot et al., 2003). After, the verbal form *appelez* /,apɛ'le/ ‘you<sub>pl</sub> call’ has three syllables and the main stress in the last pronounced syllable which is an agreement inflectional suffix, thus, the penultimate syllable cannot be stressed and the <e> has a close pronunciation in the /pɛ/ syllable. Further, the verbal form *appellerez* /a,pɛle'Re/ ‘you<sub>pl</sub> will call’ has four syllables and the main stress in the last pronounced syllable which again is an agreement inflectional suffix, and thus, the penultimate /le/ syllable cannot be stressed, however, the antepenultimate syllable can receive the secondary stress, as can be observed that the <e> has an overt pronunciation again in the /pɛ/ syllable (Estivalet & Brenner, 2012). To summarize, the French prosodic system can be formalized following the four rules in (6):

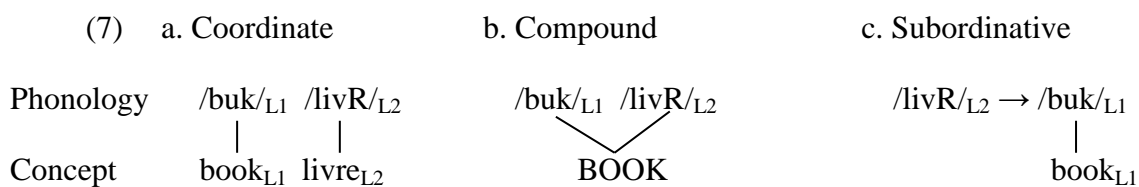
- (6)
- i. Project line 0 with one foot for each pronounced syllable;
  - ii. Assemble foot in binary constituents;
  - iii. Project line 1 with the right feet from each constituent;
  - iv. Project line 2 with the right feet final rule.

Line 2	x	x	x	x	x)
Line 1	x)	x x)	x x)	x) x x)	
Line 0	x x)	x) x x)	x x) x x)	x) x x) x x)	
Orthography	<i>prélèves</i>	<i>prélevez</i>	<i>prélèverez</i>	<i>reprélèverez</i>	
Phonology	/pRe'lɛv/	/,pRelə've/	/pRe,lɛve'Re/	/,RəpRe,lɛve'Re/	
Gloss	'deduct <sub>youSG</sub> '	'deduct <sub>youPL</sub> '	'deduct <sub>youPLfut</sub> '	'deduct <sub>youPLfut</sub> again'	

## 2.8 Bilingualism

“Language is a skin: I rub my language against the other. It is as if I had words instead of fingers, or fingers at the tip of my words. My language trembles with desire”  
(Roland Barthes, 1915-1980)

The mental lexicon organization in bilinguals has been distinguished in three main hypotheses: compound, coordinate, and subordinative, as shown in (7). The compound and subordinative systems assume a single underlying conceptual system shared by both languages, but the coordinate system assumes two conceptual systems, one for each language. Afterwards, the main difference between the compound and subordinative lexicons is that while the former accesses L2 words directly from the conceptual representations, the latter accesses the conceptual representations through corresponding L1 words (De Groot, De Bot, & Huebner, 1993). In contrast, in the coordinate lexicon, each word in L1 and L2 has its own conceptual representation.



### 2.8.1 Second Language Acquisition

It becomes clear that compound bilingualism emerges in early bilinguals who simultaneously acquire two or more languages, as in the case where the mother speaks one language and the father another language (Costa & Sebastián-Gallés, 2014). Inversely, subordinative bilingualism emerges in late L2 acquisition through language courses in which the L2 concept is translated to the L1 for language understanding. In contrast, coordinate bilingualism may be a consequence of a strict separation between the use of the languages L1 and L2 in different communicative contexts, as should also be present in advanced late L2 speakers, who construct a parallel lexicon with the specifications from the L2 concepts.

Dual-mechanism models offer interesting insights into how language is acquired and processed in bilinguals (Clahsen & Felser, 2006). The D/P model proposes that late bilinguals first acquire language knowledge by the declarative route, and only later, with large redundant accumulation of information, transfer linguistic knowledge to the procedural route (Ullman, 2001c), suggesting a transference of linguistic knowledge from the subordinative model and declarative memory to the coordinate model and procedural memory. In contrast, single-mechanism models have to postulate that all words are processed by the same route; thus, the mental lexicon should present many connections for activation and inhibition among all the units stored in L1 and L2, including both whole words and sub-lexical units (de Diego Balaguer, Sebastián-Gallés, Díaz, & Rodríguez-Fornells, 2005).

Perani and Abutalebi (2005) presented fMRI results in which neuronal areas traditionally associated with language processing (Broca's area and the basal ganglia) were equally activated during word recognition in L1 and L2. Furthermore, only late or beginner bilinguals presented additional spreading activation in the adjacent neighboring areas activated during L1 processing. This evidence shows that the same neuronal systems are used for word processing in L1 and L2; however, differences between L1 and L2 can be attributed to the cognitive resources demanded to activate the respective representations associated with the age of L2 acquisition.

## 2.8.2 Early and Late Bilinguals

Early and late bilinguals are defined based on the age at which they started to acquire a L2. In general, the critical period is defined as seven years old for L1 and 12 years old for L2, but it has been vigorously discussed and should not be considered rigid (Friederici et al., 2002; Perani, 2005). Nevertheless, here, we defined early bilinguals as the speakers who acquired their L2 during babyhood, simultaneous to their L1, and late bilinguals as the speakers who acquired their L2 during adulthood. At this point, three questions are important for the present investigation: 1) To what extent do the advanced bilinguals behave differently from native speakers? 2) Which are the behavioral differences between beginner and advanced bilinguals in the morphological processing of French inflected verbs? 3) How is the morphological processing of French verbs in L2 influenced by a closely related L1 system?

Bowden et al. (2010) showed that early bilinguals do not present any significant differences in the visual word recognition of words between L1 and L2; however, advanced later bilinguals present larger latencies in L2 than L1. Another study showed that the age of

acquisition of an L2 can be directly correlated to the participant's performance; the later an L2 is learnt, slower are the RT and higher are the error rates. Importantly, it seems that more than lexical factors, specific grammatical features of L2 also determine the effects of the age of language acquisition: young learners have more facility in the acquisition of lexical and phonological features from an L2 (Shaoul, Westbury, & Baayen, 2013).

The Shallow Hypothesis posits that early bilinguals can have the same native-speaker competence and performance in different languages; in contrast, late bilinguals would never have a deep grammatical processing and never achieve a proficiency level compared to native speakers. This hypothesis is based on four assumptions regarding how L1 and L2 processing differences can be explained: 1) lack of grammatical knowledge, 2) L1 knowledge transfer, 3) cognitive resource limitations, and 4) neuronal maturation (Clahsen & Felser, 2006). Nevertheless, it has been argued that the L2 deficit and the L1 interference should broadly summarize the L2 competence in late bilinguals. Thus, it does not mean necessarily that L2 speakers have a shallow processing of grammar, considering close languages, such as Spanish and Catalan, it should be even the case that they have a deep grammar processing. However, the limited exposition and use to the L2 obviously create deficits in that language, and late speakers should largely present an interference of the L2 in the retrieving and processing of L2 words (Frenck-Mestre, 2006).

### 2.8.3 Proficiency

Kroll, De Bot, and Huebner (1993) showed that translation from L2 to L1 is faster than the translation from L1 to L2 because the former can be made simply based on lexical representations because the L2 word is linked to the L1; in contrast, the latter must be mediated at the conceptual level, which slows the RTs. Additionally, adopting the subordinative assumptions, all L2 words have L1 equivalence, but not all L1 words find an L2 translation in the mental lexicon. Another study showed that in cross-linguistic Stroop tasks (Stroop, 1935), bilinguals present large interference in the distractor color word to be ignored printed in a different language than the color name to be produced. It was interpreted as the two languages being stored together; otherwise, this task should yield small interferences. Later, the magnitude of the Stroop interference in the L2 appeared to be related to the participants' proficiency; as the participant increases in L2 proficiency, the results present more interference within language than between languages (Kroll & Stewart, 1994).

The revised model includes connections between lexical representations between languages and connections from L1 and L2 to conceptual representations. Therefore, the model assumes that the L1 lexicon will always be larger than the L2 lexicon, as well as that the connections between L1 to conceptual representations are stronger than connections from L2 to the conceptual representations. Finally, the connections from L2 to L1 would be stronger than the connections from L1 to L2, as shown in Figure 24.

Figure 24 – Bilingual model with a larger lexicon for L1 than L2, strong connections from L1 to concepts and from L2 to L1, and weak connections from L2 to concepts and from L1 to L2 (Kroll & Stewart, 1994).

The author confirmed the prediction of this model, with translation from L2 to L1 being similar in both beginner and advanced L2 speakers, despite advanced speakers presenting a slightly better performance than beginners; in contrast, translation from L1 to L2 was significantly different between beginner and advanced speakers of L2 because beginners have weak connections from L1 to L2, as well as between L2 and concepts. Poulisse, De Bot, and Huebner (1993) analyzed the strategies of communication in bilinguals. Notably, interlingual transfer is one of the most explored strategies, with L2 speakers transferring large amounts of phonological, morphological and syntactic knowledge from the L1 (or other L2s) to the L2 target, creating an interlanguage between them. Thus, it becomes clear that if L1 and L2 are typologically similar languages and share many aspects of the various linguistic levels (e.g., Dutch and German or French and Spanish), this transfer is more successful than between languages that do not share many similarities at the different levels (e.g., Dutch and Spanish or French and German) (Carrasco-Ortiz & Frenck-Mestre, 2014; Frenck-Mestre, Osterhout, McLaughlin, & Foucart, 2008).

Regarding the morphological encoding, there is evidence that bilinguals apply a separate L1 morphology when using L1 and L2 morphology when using L2. Evidence has shown that when a speaker wrongly selects an L1 word in the place of an intended L2 word, the speaker will apply phonological and morphological processes from the L2 to make it appear more like an L2 lexical item.

## 2.8.4 Bilingual Lexicon and Grammar

How can representations and computational algorithms be shared in bilinguals? Will someone who speaks English share linguistic knowledge with someone who speaks Mandarin? What about French and Portuguese? The shared mental lexicon surely makes much more sense when representations have formal and semantic equivalence between the two languages. Thus, how bilingual speakers of closely related languages acquire morphological processing mechanisms is an interesting question that has not been sufficiently investigated. It is not clear how much of the processing mechanisms can be shared, even for typologically close languages (Schreuder, Weltens, De Bot, & Huebner, 1993).

The BIA model has four levels of activation, the input level, the letter level, the word level, and the language level, and activation coming from lower levels can activate word nodes in different languages. Thus, these lexical representations will activate the language nodes, which can provide feedback in language competition and select the correct word, as shown in Figure 25 (Grainger & Dijkstra, 1992). The BIA was developed in the BIA+, in which phonological and semantic representations were added to the orthographic ones, and most important, different roles were assigned for the language nodes, especially the language activation according to the linguistic context. These effects can be simulated and can explain how bilinguals avoid interference from the non-target language in psycholinguistic experiments (Grainger, De Bot, & Huebner, 1993). However, the BIA model does not make any prediction about the morphological processing, and probably does not consider this level of psycholinguistic processing, but predict that words are recognized based on the strength of the interactive activations between phonology, orthography, and semantics.



Figure 25 – Bilingual Interactive-Activation Model (BIA) (Dijkstra & van Heuven, 2002).

One strong hypothesis is that the underlying conceptual representation can be accessed equally by either of two surface forms; the other strong hypothesis is that knowledge about the world is organized according to the way that knowledge was acquired, in two lexicons corresponding to L1 and L2; finally, a hybrid position is that phonological and orthographic representations are separated at a surface level but share core conceptual representations at a deeper level (Snodgrass, De Bot, & Huebner, 1993). Considering decompositional models, it is likely that bilinguals have two systems of lexical morphemes and functional morphemes, with some shared representations in the surface levels and common representations in deeper levels. This means that speakers will have more facility in parts of the lexicon that share information that is more compatible than idiosyncrasies between both languages (De Bot, Schreuder, De Bot, & Huebner, 1993). In this sense, morphology may be the critical level for lexical organization considering a shared lexicon or even separated lexicons, regardless of languages. Nevertheless, if general grammatical knowledge is common between two typologically close languages in the bilingual lexicon, rules of equivalence and conversion might be stated to account for the similar core syntactic and morphological processes and for the different phonological surfaces in the different languages.

## 2.9 Sum Up

We presented above a small review of the literature related to word recognition, lexical access, visual processing, morphological processing, linguistic theory, French language, and bilingualism. We hope to have provided enough and organized information to contextualize the present thesis, its objectives, methods, and theoretical background in the investigation of the morphological processing during word recognition.

As introduced above, frequency and word length are the best predictors for RT latencies in word recognition, explaining until 45% of the human behavior. However, 50% is still remaining to be explained and we believe that grammatical factors might influence the mechanisms for word recognition, such as morphological decomposition, phonotactic, orthotactic and morphotactic consistencies, morphosyntactic features, allomorphic, morphophonological and morphographic rules. Thus, our hypothesis is that the mental lexicon is not a dictionary where words are stored as whole forms and retrieved for the insertion in the syntactic structure, but the mental lexicon might be a dynamic network of atomic complex representations of pieces of language which are computed for language interpretation (Hay & Baayen, 2005).

Therefore, the questions that motivated and drive this thesis became more clear relating the different disciplines and in the understanding of the theoretical background and empirical results. Are single- or dual-mechanism models better suited for the processing and recognition of French inflected verbs? Morphological processing is pre- or post-lexical in inflected verbs? Which mechanisms trigger word decomposition? What kind of phonological and orthographic information is represented in the mental lexicon? How the lexicon is organized in monolinguals? And in bilinguals which have close languages?

The main objective of the present thesis is to investigate the morphological processing of inflected French verbs during visual word recognition. For this purpose we developed and run five different studies presented in the Section 3. Study 1, “Frequency Effects” investigated the role of morphological cumulative frequency of stems; Study 2, “Stem Formation”, explored priming effects to determine the stem representations; Study 3, “Morphological Operations” tested the processing of the inflectional suffixes; Study 4, “Bilingual Morphological Processing” researched how late bilinguals process verbal morphology from close L1 and L2; and Study 5, “Electrocircuiting French Pseudoverbs”, tried to determine the time-course of inflectional processing in French verbs.



## 3 Studies

“The words of language, as they are written or spoken, do not seem to play any role in my mechanism of thought. The physical entities which seem to serve as elements in thought are certain signs and more or less clear images”  
(Albert Einstein, 1879-1955)

### 3.1 Study 1: Frequency Effects



# Decomposability and mental representation of French verbs

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## Abstract

In French, regardless of stem regularity, inflectional verbal suffixes are extremely regular and paradigmatic. Considering the complexity of the French verbal system, we argue that all French verbs are polymorphemic forms that are decomposed during visual recognition independently of their stem regularity. We conducted a behavioural experiment in which we manipulated the surface and cumulative frequencies of verbal inflected forms and asked participants to perform a visual lexical decision task. We tested four types of verbs with respect to their stem variants: a. fully regular (*parler* ‘to speak’, [parl-]); b. phonological change e/ɛ verbs with orthographic markers (*répéter* ‘to repeat’, [répét-] and [répèt-]); c. phonological change o/ɔ verbs without orthographic markers (*adorer* ‘to adore’, [ador-] and [adɔr-]); and d. idiosyncratic (*boire* ‘to drink’, [boi-] and [buɥ-]). For each type of verb, we contrasted four conditions, forms with high and low surface frequencies and forms with high and low cumulative frequencies. Our results showed a significant cumulative frequency effect for the fully regular and idiosyncratic verbs, indicating that different stems within idiosyncratic verbs (such as [boi-] and [buɥ-]) have distinct representations in the mental lexicon as different fully regular verbs. For the phonological change verbs, we found a significant cumulative frequency effect only when considering the two forms of the stem together ([répét-] and [répèt-]), suggesting that they share a single abstract and underspecified phonological representation. Our results also revealed a significant surface frequency effect for all types of verbs, which may reflect the recombination of the stem lexical representation with the functional information of the suffixes. Overall, these results

indicate that all inflected verbal forms in French are decomposed during visual recognition and that this process could be due to the regularities of the French inflectional verbal suffixes.

**Keywords:** morphology, regularity, decomposition, lexical access, frequency effects, verb inflection

## 1 Introduction

The surface frequency effect, which reflects differences in word recognition as a function of form frequency, is one of the most reliable phenomena described in the psycholinguistic field in the last 35 years (Taft and Forster, 1975; Taft, 1979; Burani et al., 1984; Meunier and Segui, 1999b; Domínguez et al., 2000; Taft, 2004). Polymorphemic words, in addition to their surface frequency, are characterised by their cumulative frequency (also called lemma frequency), which is defined as the sum of the frequencies of all affixed words that carry that stem (e.g., for the stem [*parl-*], the sum of the surface frequency of *parlons* ‘we speak’ + the surface frequency of *parlez* ‘you speak’ + the surface frequency of *parlent* ‘they speak’, etc.). Therefore, word and morpheme frequencies are directly related to the time spent for word recognition, with more frequent words being recognised faster than less frequent ones (Taft and Forster, 1975). The effects of the different frequencies of polymorphemic words are of great interest in the investigation of morphemic representations in the mental lexicon and morphological decomposition during word processing (Colé et al., 1989; Domínguez et al., 2000), especially in languages with rich and paradigmatic morphological systems. The cumulative frequency effect is interpreted as reflecting a decomposition process and shows the influence of the morpheme frequency in retrieval and lexical access (Taft and Forster, 1975; Taft, 2004), whereas the surface frequency effect is interpreted as reflecting either the time spent to retrieve and access a whole word in the mental lexicon (Manelis and Tharp, 1977; Butterworth, 1983) or the morphosyntactic recombination process between stem and affixes (Taft, 1979; 2004).

In this research, we investigated the mental representation of French verb stems, their allomorphy (the alternative forms of a morpheme depending on its phonological and morphological context) and verbal decomposability. Unlike the English verbal system, which is generally divided into two groups (regular and irregular verbs) with few suffixes (i.e., walk[s], walk[ed] and walk[ing]) (Stanners et al., 1979; Aronoff, 1994), the French verbal

system has different degrees of stem regularity and a paradigmatic set of suffixes for tenses and agreements. Similarly to other Romance languages (Oltra-Massuet, 1999; Domínguez et al., 2000; Say and Clahsen, 2002; Veríssimo and Clahsen, 2009), French has three groups of verbs (see Table 1). However, in contrast to most Romance languages, the French verbal groups are not explicitly defined in function of the theme vowels. Moreover, French has a particular iambic prosodic system that directly influences the phonetic production of the stems and inflectional suffixes in a predictive way (Aronoff, 2012; Andreassen and Eychenne, 2013). In particular, the pronunciation of the syllables to the right of the stem produces prosodic consequences, which are reflected in phonetic production. Thus, for verbs from the first group that undergo phonological changes, the last vowel of the stem is open pronounced (/ɛ/ and /ɔ/) if the stem is merged with a non-pronounced suffix (e.g., [-e], [-es], [-ent] as in [rɛpɛt]e /Re'pɛt/ 'I/he/she repeat(s)') but is close pronounced (/e/ and /o/) if the stem is merged with a suffix that has a pronounced vowel (e.g., [-ons], [-ez], [-ai], [-i], [-er] as in [rɛpɛt]ons /Repe'tɔ̃/ 'we repeat') (Touratier, 1996). A question that remains open is whether different phonological forms of a verb have different lexical representations or whether they share an abstract or underspecified representation.

The first verbal group in French is regular concerning its conjugations and is characterised by the infinitive ending [-er]. The second group is also regular and is characterised by the infinitive ending [-ir] associated with the realisation of the morpheme [-ss-] before suffixes beginning with vowels. The third group comprises irregular verbs, including verbs with different infinitive endings (e.g., [-dre], [-ire], [-oir], etc.) and a different number of stems per verb (Kilani-Schoch and Dressler, 2005; Aronoff, 2012). Therefore, the first group has verbs with just one stem, such as *ramer* 'to paddle'. The only modification that is observed within a sub-group of stems is a phonological predicted alternation in the stem (these verbs can also be called morpho-phonological verbs), such as the verb *céder* 'to cede' (e.g., [cɛd]es /'sɛd/ 'you cede', [cɛd]ons /se'dɔ̃/ 'we cede') (Halle and Idsardi, 1996; Andreassen and Eychenne, 2013). Stems from the second group are always the same in the full inflectional system (e.g., [fini]r 'to finish'). Finally, the third group includes verbs with just one stem, such as *rendre* 'to render', verbs with small changes in the stem, such as *écrire* 'to write' (e.g., [ɛcri]t 'he/she writes', [ɛcriv]ons 'we write'), and verbs with idiosyncratic stem allomorphs, such as *devoir* 'must' (e.g., [doi]s 'I/you must', [dev]ons 'we must', [doiv]ent 'they must') (Touratier, 1996). Unlike stems that carry the lexical meaning, the morphosyntactic inflectional system of tense and agreement suffixes in French is extremely paradigmatic and can be easily detached from the stem to which it is merged



(Meunier and Marslen-Wilson, 2004). Thus, all verbal inflected forms in French can be decomposed based on their regular and salient inflectional system of suffixes, and this evident morphosyntactic decomposition may determine the mental representation of verbal stems.

	1st Group			2nd Group	3rd Group		
Infinitif	ramer	céder	moquer	finir	rendre	écrire	devoir
Je	rame	cède	moque	finis	rends	écris	dois
Tu	rames	cèdes	môques	finis	rends	écris	dois
Il	rame	cède	moque	finit	rend	écrit	doit
Nous	ramons	cédons	moquons	finissons	rendons	écrivons	devons
Vous	ramez	cédez	moquez	finissez	rendez	écrivez	devez
Ils	rament	cèdent	môquent	finissent	rendent	écrivent	doivent

Table 1 - Examples of the three French verbal groups conjugated in the present tense showing the stem regularity and the suffix paradigms.

The first objective of the current work was to determine whether the systematic French verbal inflectional system underlies the morphological decomposition of all forms on visual recognition (Rastle and Davis, 2008) or whether inflected verbs can be accessed as whole words. The second objective was to investigate how stems are represented in the mental lexicon in function of their regularity (Bybee, 1995). For this purpose, participants performed a visual lexical decision task on French inflected verbs. We manipulated the surface and cumulative frequencies for four types of stem variants: a. fully regular verbs from the first group (*parler* ‘to speak’, one form [*parl-*]); b. phonological change *e/ε* verbs from the first group with orthographic markers (*répéter* ‘to repeat’, two forms [*répét-*] /*repet-*/ and [*répèt-*] /*repet-*/); c. phonological change *o/ɔ* verbs from the first group without orthographic markers (*adorer* ‘to adore’, two forms [*ador-*] /*ador-*/ and /*adɔr-*/); and d. idiosyncratic verbs from the third group with different stems (*boire* ‘to drink’, two forms [*boi-*] and [*buv-*]). We tested two different phonological change verbs (i.e., with and without orthographic markers) because the orthographic markers can be a strong hint for phonetic realisation (Kilani-Schoch and Dressler, 2005) in visual stimulation, yielding different results (Seidenberg, 1992; Rastle and Davis, 2008).

To explain the word-recognition process, different models have been suggested to account for morphological processing in lexical access. The first type of model proposes an obligatory decomposition process for polymorphemic words upon lexical retrieval and recognition (Halle, 1973; Taft and Forster, 1975; Taft, 1979; Halle and Marantz, 1993; Marantz, 2013) in which the components of polymorphemic words are represented at the form and morphemic levels. The meaning of the whole word form is retrieved when the lexical information of the stem is combined with the morphosyntactic information of the affixes. The second type of model proposes an exclusively associative whole-word lexical access (Manelis and Tharp, 1977; Butterworth, 1983). This type of model includes the connectionist model, with its different variations (Rumelhart and McClelland, 1986; Seidenberg, 1992; Baayen et al., 2011), basically suggesting that morphology emerges from the overlap between meaning, phonology and orthography. The third model type aggregates both decompositional and associative lexical access to propose a dual-route model (Caramazza et al., 1988; Baayen et al., 1997; Clahsen, 1999; Pinker, 1999; Clahsen, 2006).

The dual-route models, such as the Augmented Address Model (AAM) (Burani et al., 1984; Caramazza et al., 1988), the Race Model (RM) (Baayen et al., 1997; Schreuder and Baayen, 1997), and the Words and Rules model (W&R) (Pinker, 1999; Pinker and Ullman, 2002), have been supported by a significant amount of research in different languages in the past few years, with different specifications for each of their versions. However, more specifically for our study, the Minimalist Morphology model (MM) (Wunderlich, 1996) uses the morpheme-based assumption, highlighting the computational route by proposing that regular inflected forms are established by merging constant lexical entries and affixes and that irregular inflected forms are represented by subnodes of lexical entries containing variables (Clahsen, 1999; Clahsen, 2006). Empirical research has been conducted to better understand the general principles of word recognition, including specific morphological parameters that drive the morphological processing and representation in different languages (Beard, 1995). These examinations in verbal inflection have been conducted in English with the now-famous English past tense debate (Stanners et al., 1979; Rumelhart and McClelland, 1986; Marslen-Wilson and Tyler, 1998; Pinker, 1999; McClelland and Patterson, 2002; Pinker and Ullman, 2002; Fruchter et al., 2013), German (Clahsen, 1999), Dutch (Baayen et al., 1997; Schreuder and Baayen, 1997), and Finnish (Leinonen et al., 2008). Romance languages have also been investigated, including Spanish (Domínguez et al., 2000), Catalan (Oltra-Massuet, 1999), Portuguese (Sicuro Corrêa et al., 2004; Veríssimo and Clahsen, 2009), Italian (Burani et al.,

1984; Caramazza et al., 1988; Orsolini and Marslen-Wilson, 1997; Say and Clahsen, 2002), and French (Meunier and Marslen-Wilson, 2004; Meunier et al., 2008; Meunier et al., 2009).

Altogether, the literature clearly shows that morphological processing has a fundamental role in lexical access, especially in inflected polymorphemic words in which the computational system and the mental lexicon interact for word recognition (Halle, 1973; Colé et al., 1997; Marslen-Wilson and Tyler, 1998; Clahsen, 1999). Concerning verbal form identification, findings in English, Dutch, and German are clear, with multiple sources of evidence in favour of a lexical associative process for irregular words and a rule-based process for regular ones. These findings suggest that regular inflected words are completely combinatorial, whereas irregular inflected words are internally structured and represented in the mental lexicon (Wunderlich, 1996; Baayen et al., 1997; Pinker, 1999). However, based on a facilitatory priming effect for irregular pairs such as *fell* – *fall* in masked priming, Crepaldi et al. (2010) recently challenged the idea of an exclusively semantic relationship between the irregularly inflected forms and their base forms (see also Forster et al. (1987)). These authors proposed a shared representation that underlines both forms at the lemma level where inflected words share their representation irrespective of orthographic regularity (Crepaldi et al., 2010; McCormick et al., 2008). The results observed within Romance languages with a richer verbal morphology are somewhat more puzzling than these results in Germanic languages. For example, using a cross-modal priming paradigm in Italian, Orsolini and Marslen-Wilson (1997) did not report any difference between effects observed for regular (e.g., *amarono* – *amare*, ‘they loved’ – ‘to love’) and irregular sub-class (e.g., *presero* – *prendere*, ‘they took’ – ‘to take’) verbs (but see Say and Clahsen (2002)). In contrast, findings in Portuguese have supported dual-route models, differentiating the lexicon and computational systems (Sicuro Corrêa et al., 2004; Veríssimo and Clahsen, 2009). These language-specific differences may reflect cross-linguistic specificities that are broadly noted in the morphological components (Beard, 1995; Chomsky, 1995; Marslen-Wilson, 2007).

Very few studies have assessed French inflectional categories to understand their lexical representation, access, and processing. Meunier and Marslen-Wilson (2004) used cross-modal and masked priming paradigms and showed that French inflected verbal forms present a facilitatory priming effect independently of their degree of stem regularity and allomorphy. In the cross-modal priming experiment, the priming effects were on the order of 51 ms for all types of verbs. In the masked priming experiment, significant priming effects varied from 16 ms up to 32 ms, depending on specific conditions. The authors concluded that morphologically related primes in French significantly facilitated response times (RTs) for all

type of verbs, suggesting that decomposition takes place regardless of stem regularity. However, the variability of the effects observed in the masked priming experiment may suggest a more complex picture because the stem included in a prime such as *buvais* ‘I/you drank’ overlaps minimally with the target *boire* ‘to drink’. Thus, if *[buv]ais* is decomposed, the remaining stem *[buv-]* does not overlap with the target stem *[boi-]*, as in the case of fully regular verbs (e.g., *[pass]ais* - *[pass]er* ‘I/you passed’ – ‘to pass’). Therefore, the priming effects for idiosyncratic verbs, much like the system for their stem representation in the mental lexicon, remains open to question.

The use of priming techniques may cause specific experimental effects due to form-related processing that overlaps between priming and target (Allen and Badecker, 2002). One effective method to test verbal form decomposition is to measure the influence of the surface and cumulative frequencies on RT modulation (Taft and Forster, 1975; Taft, 1979; Burani et al., 1984; Colé et al., 1989; Schreuder and Baayen, 1995; Baayen et al., 1997; Colé et al., 1997; Schreuder and Baayen, 1997; Meunier and Segui, 1999a; Domínguez et al., 2000; Taft, 2004). Therefore, we conducted a visual lexical decision task experiment in which we manipulated the cumulative and surface frequencies of verbs that differed in stem regularity.

In a seminal work in English word recognition, Stanners et al. (1979) showed that words matched in surface frequency have RTs modulated in the function of the cumulative frequency, with more frequent stems being recognised faster than less frequent ones. In Dutch, Schreuder and Baayen (1997) found the same type of results between high and low cumulative frequency words matched in the singular form in medium surface frequency. In a frequency study investigating Italian inflected verbs, Burani et al. (1984) obtained a significant difference between words with high and low cumulative frequencies matched in low surface frequency. Therefore, verbal inflection processing may be strongly related to cumulative frequency given its influence in the morphemic representation (Aronoff, 1994).

In French, as in other Romance languages, the right side of a verb has verbal suffixes that are paradigmatic realisations of morphosyntactic features of tense and agreement. The left side of the verb has a stem containing the root, which provides lexical information (Halle and Marantz, 1993; Kilani-Schoch and Dressler, 2005; Aronoff, 2012). In our experimental paradigm, we tested four verb types. (a) Fully regular verbs from the first group that have just one stem representation in the mental lexicon, which can be merged with the complete inflectional paradigm (Bybee, 1995). Thus, our hypothesis is that verbs are decomposed prior to lexical access, yielding a cumulative frequency effect between the forms of two regular

verbs matched on their surface frequencies but with different cumulative frequencies. (b) Phonological change e/ɛ verbs with orthographic markers are verbs from the first group but with two different predictable phonetic outcomes from the last <e> of the stem according to which suffix the stem is merged with (e.g., [mèn]es ‘you lead’, [men]ons ‘we lead’). They have an orthographic marker associated with the open phonetic production (i.e., <è>, <\_ll> or <\_tt>). (c) Phonological change o/ɔ verbs without orthographic markers are verbs from the first group that present a predictable phonetic alternation in the last <o> of the stem but without any orthographic marker (e.g., [dévɔr]es ‘you devour’, [dévɔr]ons ‘we devour’) (Kilani-Schoch and Dressler, 2005; Andreassen and Eychenne, 2013). For these two verbs types, the question is whether French speakers have two different phonetic representations of the stem in their mental lexicon or one phonological abstract underspecified representation of the stem that receives its phonetic form only in the spell-out of the word (Halle and Marantz, 1993; Marslen-Wilson and Zhou, 1999; Embick, 2013). This point was tested by contrasting the cumulative frequencies of different phonetic stem alternations. Finally, (d) idiosyncratic verbs from the third group have two or more unpredictable stem allomorphs to which the suffixes are merged (e.g., [peu]t ‘he/she can’, [pouv]ons ‘we can’, [pu] ‘could’, [puiss]e ‘I/he/she can’). Although previous results from Meunier and Marslen-Wilson (2004) suggested that these verbal forms are processed as fully regular ones, contrasting the cumulative frequencies of the different stems will allow us to test whether these idiosyncratic verbs have two or more different stem representations in the mental lexicon.

## 2 Materials and Methods

### 2.1 Participants

Thirty-two adult native speakers of French between the ages of 18 and 32 (mean age: 20.31, 16 females) took part in this experiment as volunteers. All of the participants were right-handed, had normal hearing, normal or corrected-to-normal vision, no history of any cognitive disorder, and were undergraduate students at the *Université Lumière Lyon 2*. The participants did not know the purpose of the research and provided written consent to take part in the experiment as volunteers.

## 2.2 Materials and Design

We asked the participants to perform a lexical decision task on visually presented items. The participants gave their responses on a computer keyboard using two hands, a right-hand button ‘yes’ to indicate existing words and a left-hand button ‘no’ to indicate pseudowords. All of the words were chosen from the French corpus *Lexique 3* <<http://www.lexique.org/>> (New et al., 2004), which gives the frequency of the whole-word form (surface) and the frequency of the lemma per million words. In our study, the stem cumulative frequency was defined by summing the surface frequency of all inflected forms from each stem of interest.

To observe the different effects on the RTs as a function of the whole-word form and stem frequencies, we thoroughly manipulated and matched the cumulative and surface frequencies in the high and low ranges (Taft, 1979; Burani et al., 1984; Colé et al., 1989; Meunier and Segui, 1999a) as shown in Table 2.

Verb type	High cumulative frequency > 140		Low cumulative frequency < 80	
	High surface frequency > 5	Low surface frequency < 0.5	High surface frequency > 5	Low surface frequency < 0.5
a. Fully regular	parlait	parliez	chante	chantez
b. Phono. e/ε	répétait	répétions	répète	répètes
c. Phono. o/ɔ	adorais	adoriez	adore	adores
d. Idiosyncratic	buvais	buviez	boivent	boives

Table 2 - Examples of experimental items according to verb type and frequency conditions.

Eighty stem pairs from the four verb types researched were selected, with 20 pairs for each verb type. All of the experimental words were inflected French verbs. We avoided inflected forms from the *passé simple*, the *subjonctif imparfait* and the participles because of their morphological productivity and specificity. The four verb types investigated were as follows: a. fully regular verbs, b. phonological change e/ε verbs with orthographic markers, c. phonological change o/ɔ verbs without orthographic markers, and d. idiosyncratic verbs. For the fully regular verbs, we did not use a stem pair from the same verb because these verbs have only one stem; instead, we used two different verbs with the same surface frequency.

For the phonological change verbs, we calculated the stem cumulative frequency by summing all forms of each stem's phonetic realisation. For the idiosyncratic verbs, we summed all forms of each allomorphic stem. We manipulated the cumulative and surface frequencies to match the four different conditions: two conditions with high cumulative frequency and high or low surface frequencies and two conditions with low cumulative frequency and high or low surface frequencies.

The experimental words in all verb types and conditions were not homographic with any other existent forms in French and had between six and eleven letters, between three and nine phonemes, and between one and four syllables. The words had an orthographic neighbourhood size between one and three, as measured by the orthographic Levenshtein distance (OLD20), which compares words between all pairs of words in the lexicon, even with different lengths (Yarkoni et al., 2008). All of the experimental words were matched in their number of letters, number of phonemes, number of syllables, and OLD20 (see Table 3). The high cumulative frequency condition contained words with stem cumulative frequencies greater than 140, whereas the low cumulative frequency condition contained words with stem cumulative frequencies lower than 80. The high surface frequency condition had words greater than five form frequencies, whereas the low surface frequency condition had words fewer than 0.5 form frequencies.

A set of 320 pseudowords was added to the 320 experimental items to produce the non-existent word response such that the experiment had 640 stimuli in total. The pseudowords were constructed by merging a non-existent but possible stem to an existent verbal inflectional suffix in French (pseudoverbs) (e.g., \**[[pors]ent]*, \**[[[lomb]i]ons]*). Four different lists were constructed in a strict pseudo-random order to counterbalance the sequence of stimulus presentation between conditions. Each list was performed by eight participants. The lists had the following criteria: a. a stimulus was never preceded by another stimulus starting with the same letter, b. there were at maximum three words or pseudowords presented in sequence, c. there were at least 20 stimuli between words from the same lemma, and d. there were at least five stimuli between words/pseudowords with the same suffixes.

Verb type	Cum.	Surf.	Cumulative frequency	Surface frequency	Letters	Phonemes	Syllables	OLD20
a. Fully regular	High	High	278.38	6.34	7.90	5.10	2.30	1.90
	High	Low	278.38	0.34	8.10	6.15	2.85	2.03
	Low	High	62.04	6.23	7.95	5.50	2.50	1.95
	Low	Low	62.04	0.28	8.20	6.20	3.00	1.95
b. Phono. e/ɛ	High	High	236.41	6.12	8.10	6.20	3.00	2.00
	High	Low	236.41	0.43	7.90	5.60	2.70	2.07
	Low	High	64.25	6.02	7.95	5.85	2.80	2.10
	Low	Low	64.25	0.35	8.20	6.30	3.00	2.01
c. Phono. o/ɔ	High	High	215.87	5.96	8.20	5.90	2.85	1.98
	High	Low	215.87	0.19	8.15	5.65	2.70	2.11
	Low	High	60.29	6.12	7.90	5.50	2.00	1.95
	Low	Low	60.29	0.23	8.15	5.70	2.75	1.95
d. Idiosyncratic	High	High	258.84	6.09	8.35	6.80	2.65	2.08
	High	Low	258.84	0.36	8.20	6.45	2.50	2.15
	Low	High	61.85	6.18	8.20	6.40	2.65	2.00
	Low	Low	61.85	0.28	8.10	6.20	3.00	1.98

Table 3 - Stimulus frequencies, letters, phonemes, syllables and OLD20.

## 2.3 Procedure

Participants were tested individually in a quiet room in the library at the *Université Lumière Lyon 2*. We used the E-Prime v2.0 Professional® (Schneider et al., 2012) software to construct the experiment as well as for stimulus presentation and data collection. Each trial followed the same sequence. First, a fixation point was displayed in the centre of the screen for 500 ms at the same time as a “bip” sound was played. Immediately following the fixation offset, the target stimulus was displayed in the centre of the 15” LCD screen in 18 point



Courier New font in white letters against a black background. The target stimuli were presented in upper-case letters to avoid extra processing on the French accents. The RT recording started with the onset of the target stimulus presentation, which remained on the screen for 2000 ms or until the participant's response. After the target stimulus disappeared, the next trial started with the presentation of the fixation point. Participants were asked to perform a visual lexical decision task in which they decided whether the stimulus was an existent or a non-existent word (pseudoword) in each trial, pushing one of two keys as quickly and accurately as possible to indicate their choice. If the stimulus presented was an existent word, the participants were asked to push the right button; if the stimulus was a non-existent word (pseudoword), they were asked to push the left button. The experiment started with an instructional screen followed by a practice phase with eight stimuli. One break was provided in the middle of the experiment after 320 trials. The entire experiment lasted approximately 18 minutes.

### 3 Results

For the experimental words, the by-participant average RT of correct acceptance was 695 (197) ms. Incorrect responses (9.62%) were removed from further analysis. Responses faster than 400 ms or slower than 1800 ms were also discarded (0.36%). Overall, 9.94% of the responses from the original data were discarded prior to statistical analysis.

RTs were logarithmically transformed to normalise their distribution. We conducted a mixed-effect model analysis (Baayen et al., 2008) on the data, with the logarithm of the RTs as the dependent variable in one analysis, and the accuracy as the dependent variable and a binomial distribution specified in another. Participants and Items were the random variables, and the Cumulative Frequency (high vs. low), Surface Frequency (high vs. low), and Verb Type (a. fully regular, b. phonological change e/ε verbs with orthographic markers, c. phonological change o/ɔ verbs without orthographic markers, and d. idiosyncratic) were the fixed-effect variables. The general RT means with their standard deviations in parenthesis and the error rates for each type of verb and each condition based on the by-participant analysis are displayed in Table 4.

Verb type	High cumulative frequency				Low cumulative frequency			
	High surface frequency		Low surface frequency		High surface frequency		Low surface frequency	
	RT (ms)	Error (%)	RT (ms)	Error (%)	RT (ms)	Error (%)	RT (ms)	Error (%)
a. Fully regular	662 (171)	1.52	688 (180)	2.57	679 (168)	2.01	707 (197)	2.65
b. Phono. e/ε	673 (186)	2.03	698 (187)	2.69	671 (176)	2.03	701 (201)	2.07
c. Phono. o/ɔ	678 (181)	1.76	702 (198)	3.44	681 (179)	2.66	704 (168)	2.03
d. Idiosyncratic	681 (188)	1.87	697 (195)	2.50	698 (187)	2.54	716 (192)	2.73

Table 4 - Overall RT means, standard deviations, and error rates for each type of verb and condition.

### 3.1 RT Results

Overall, we found a significant effect for surface frequency ( $F(1,293) = 22.494$ ,  $p < 0.001$ ) and cumulative frequency ( $F(1,293) = 12.861$ ,  $p < 0.01$ ), but we did not find a significant effect between the different verb types ( $F(3,293) = 0.462$ ,  $p = 0.709$ ). Regarding the general interactions, the only one that reached significance was between word type and cumulative frequency ( $F(3,293) = 8.238$ ,  $p < 0.05$ ). This significant interaction effect will be further discussed by means of the different representations between regular and idiosyncratic verbs compared with phonological change verbs. Our main goal was to determine how the RT differences behaved for each verb type in terms of the surface and cumulative frequencies.

Planned comparisons given by the mixed effect model showed that fully regular verbs demonstrated a main effect for surface frequency, with high-frequency words being recognised faster than low-frequency words. This effect of 26 ms for high cumulative frequency words and 27 ms for low cumulative frequency verbs was significant ( $t(292) = 2.942$ ,  $p < 0.01$ ). There was also a main effect for cumulative frequency, with high-frequency words having faster responses than low-frequency words. This effect of 17 ms for high surface frequency verbs and 19 ms for low surface frequency verbs was also significant ( $t(289) = 2.442$ ,  $p < 0.05$ ). There was no significant interaction between cumulative and surface frequencies ( $t(294) = 0.181$ ,  $p = 0.857$ ), suggesting that the two effects are independent of each other.

For phonological change e/ε verbs with orthographic markers, there was a significant effect for surface frequency ( $t(293) = 2.802$ ,  $p < 0.05$ ) of 25 ms in high cumulative frequency and 30 ms in low cumulative frequency verbs. However, there was no cumulative frequency

effect ( $t(290) = 0.521, p = 0.603$ ), with a negative difference of -2 ms in high surface frequency verbs and only 3 ms in low surface frequency verbs, indicating that different frequencies in the stems of the phonological change e/ε verbs with orthographic markers do not elicit different RTs for word recognition. There was no significant effect on the interaction between cumulative and surface frequencies ( $t(291) = 0.535, p = 0.593$ ).

For phonological change o/ɔ verbs without orthographic markers, there was a significant effect for surface frequency ( $t(294) = 2.406, p < 0.01$ ), confirming the surface effect. This effect was 24 ms in high cumulative frequency verbs and 23 ms in low cumulative frequency verbs. However, there was no cumulative frequency effect ( $t(292) = 0.078, p = 0.938$ ), with a difference of only 3 ms in high surface frequency and 2 ms in low surface frequency verbs. There was no significant effect for the interaction between cumulative and surface frequencies ( $t(294) = 1.358, p = 0.175$ ).

Finally, idiosyncratic verbs showed a main effect in the surface frequency of 16 ms in high cumulative frequency and 18 ms in low cumulative frequency verbs. This effect was significant ( $t(292) = 3.397, p < 0.01$ ), confirming the surface effect. Importantly, there was also a significant main effect in cumulative frequency of 17 ms in high surface frequency verbs and 19 ms in low surface frequency verbs ( $t(292) = 2.312, p < 0.05$ ). There was no significant effect on the interaction between cumulative and surface frequencies ( $t(294) = 0.149, p = 0.882$ ), suggesting that the surface and cumulative frequency effects are independent.

## 3.2 RT Discussion

Overall, we systematically observed a surface frequency effect for the four types of verbs tested; however, the picture for the cumulative frequency is different. Although its effect is clearly observed in the fully regular and idiosyncratic verb types, it does not appear in either type of phonological change verbs (with or without orthographic markers). This result explains why we found a significant interaction between verb type and cumulative frequency in the general analysis: regular and idiosyncratic verbs have different cumulative frequency behaviours compared with phonological change verbs. Because we did not find any cumulative frequency effect in this last verb type, phonetic alternations in the stem production may not be considered to be differently represented in the mental lexicon (Marslen-Wilson and Zhou, 1999; Embick, 2013). Therefore, these phonetic alternations do not result from

different phonological representations but are most likely due to phonological abstract representations that receive their phonetic form after suffix computation in a later stage (Embick and Halle, 2005). To test this interpretation, we reconsidered the cumulative frequency for the stems as being the total cumulative frequency (i.e., the lemma frequency provided by the corpus), meaning the sum of both phonological changes for each type of verb (e.g., for the verb *lever* ‘to lift’, the cumulative frequency of the stem *[lev-]* of 347 per million was added to the cumulative frequency of the stem *[lev-]* of 91 per million, resulting in a total cumulative frequency of 438 per million for all of its verb forms). We then conducted a post-hoc analysis through a new mixed-effect model (Baayen et al., 2008) that used the frequency values of surface and cumulative frequencies as continuous predictors. The logarithm of the RTs was the dependent variable, Participants and Items were the random variables, and the TotalCumulativeFrequency (numeric), SurfaceFrequency (numeric), and Verb Type (b. phonological change e/ε verbs with orthographic markers, and c. phonological change o/ɔ verbs without orthographic markers) were the fixed-effect variables.

For phonological change e/ε verbs with orthographic markers in this analysis, there was a main effect of surface frequency ( $t(291) = 2.495, p < 0.01$ ). Most importantly, there was a main effect of total cumulative frequency ( $t(292) = 2.929, p < 0.01$ ), confirming that the cumulative frequency of the phonological change verbs should not be considered separately between the different phonetic stem realisations. There was no significant effect for the interaction between total cumulative and surface frequencies ( $t(287) = 1.055, p = 0.292$ ).

For phonological change o/ɔ verbs without orthographic markers, similarly to the phonological change e/ε verbs, there was a main effect for surface frequency ( $t(295) = 2.104, p < 0.01$ ), and most importantly, there was also a main effect of total cumulative frequency ( $t(288) = 2.238, p < 0.05$ ), definitively confirming the total cumulative frequency effect in phonological change verbs. There was no significant effect for the interaction between total cumulative and surface frequencies ( $t(292) = 0.868, p = 0.386$ ), suggesting that both effects are independent.

These results confirm that phonological stem changes have only one abstract phonological underspecified representation in the mental lexicon (Marslen-Wilson and Zhou, 1999) and that the different phonetic productions are reflexes of phonological rules driven by the merger operation between the stem and suffixes (Embick, 2013).

### 3.3 Error Rate Results

Fully regular verbs had an error rate of 8.12%, phonological change e/ɛ verbs had an error rate of 8.83%, phonological change o/ɔ verbs had an error rate of 9.88%, and idiosyncratic verbs had an error rate of 9.65%. High and low surface frequencies had error rates of 8.24% and 11.01%, respectively, whereas high and low cumulative frequencies had error rates of 7.79% and 11.45%, respectively. Overall, we did not find any significant error rate difference between the verb types ( $F(3,303) = 0.216, p = 0.885$ ). However, we did find significant error rate differences between the surface frequencies ( $F(1,303) = 5.202, p < 0.05$ ), suggesting that words with higher surface frequencies are not only recognised more quickly but are also more easily recognised in visual stimulation as well as in the cumulative frequency ( $F(1,303) = 9.149, p < 0.01$ ), suggesting that more frequent stems are more easily recognised than less frequent ones. No interaction reached significance, suggesting that verb type, surface frequency and cumulative frequency are independent.

## 4 General discussion

In this work we investigated the mental representations and decomposability of French verbs. French is a rich morphological language in terms of lexical morphemes with fully regular stems, phonological stem changes, and idiosyncratic allomorphy in the stem (Kilani-Schoch and Dressler, 2005; Aronoff, 2012). We conducted an experiment in which the cumulative and surface frequencies were manipulated using high and low frequency conditions. Participants were asked to perform a lexical decision task as quickly and accurately as possible on visual items. The RTs and error rates were then analysed as a function of our hypothesis.

We observed surface frequency effects for all types of verbs tested. More importantly, we observed cumulative frequency effects for the fully regular verbs from the first group and for the idiosyncratic verbs from the third group. The phonological change verbs presented slightly different results, yielding no cumulative frequency effect when the frequencies of the two phonetic stem forms were computed separately. However, the phonological change verbs yielded a significant total cumulative frequency effect when the cumulative frequency count included all of the conjugated forms of the verb, regardless of the phonetic form alternations.

These results shed light on how verbal inflected forms are processed and how stems are represented in the mental lexicon depending of their type of regularity.

## 4.1 Regularity

Fully regular French verbs from the first group have a single stem on which the verbal inflectional paradigm is based. Due to the paradigmatic system of verbal suffixes, it is extremely easy to identify and decompose the lexical morpheme (stem) from the inflectional endings containing morphosyntactic features (suffixes) (Bybee, 1995). Confirming our hypothesis, the significant cumulative frequency effect indicates that it is a predictive factor in word recognition, and its manipulation results in RT modulations (Taft, 1979). In this context, accordingly to Taft (2004, p.747), the surface frequency effect “is explained in terms of the ease with which the information associated with the stem can be combined with the information associated with the affix”.

## 4.2 Phonological Changes

Unlike fully regular verbs, phonological change verbs have predictable alternations in their phonetic forms according to the phonological properties of the suffix to which the stem is merged (Embick, 2013). Therefore, the lack of an effect in the cumulative frequency between the phonetic alternation forms and the significant effect of total cumulative frequency confirms our hypothesis that verbs with phonological changes have an abstract phonological underspecified representation that is contacted during processing. Verbs with phonological changes are decomposed, and the different phonetic forms activate a single phonological underspecified stem (Marslen-Wilson and Zhou, 1999). An alternative hypothesis is that both different phonetic stems have a rule-based relation and only one of them is stored in the lexicon.

## 4.3 Idiosyncrasy

For idiosyncratic verbs, similarly to the other verb types, the surface frequency effect should be interpreted as the recombination between the stem and affixes (Taft, 1979; 2004). Interestingly, we found a significant main effect in the cumulative frequency that can be

broadly interpreted as differential access to different mental representations of the idiosyncratic stem allomorphs (Forster et al., 1987). However, this finding also suggests that even idiosyncratic known verbs are decomposed during visual recognition. These results are incompatible with models postulating that known words or irregular words are accessed by the direct whole-word route, such as the AAM (Caramazza et al., 1988) and the W&R (Pinker, 1999). Our results are in accordance with the earlier priming study in French on inflected verb recognition (Meunier and Marslen-Wilson, 2004). In French, even idiosyncratic verbs from the third group are decomposed due to the paradigmatic verbal inflectional system of suffixes (Bybee, 1995; Kilani-Schoch and Dressler, 2005).

## 4.4 Decomposability and Regularity

According to Rastle and Davis (2008), the recognition of polymorphemic words in visual modality begins with a morphological decomposition based on an analysis of orthography. Thus, because the orthographic regularity and relationships across the stems and the suffixes are extremely consistent in French (Bybee, 1995), we suggest that morphological decomposition is triggered more by the decomposability of verbal forms than by their regularity *per se*. Therefore, we argue that all French inflected verbs are first decomposed to their stem and suffixes and then these morphemes are accessed according to their cumulative frequency, generating the cumulative frequency effect. This decomposition activates lexical and morphosyntactic information systems, which are later recombined and verified for word recognition, generating the surface frequency effect. This assumption strongly supports the full-decomposition models (Halle, 1973; Taft, 1979; Halle and Marantz, 1993; Taft, 2004; Embick and Halle, 2005; Marantz, 2013) or the dual-route models, with a special emphasis on the combinatorial route (Wunderlich, 1996; Baayen et al., 1997; Orsolini and Marslen-Wilson, 1997; Clahsen, 1999). In this case, the bound-stems are stored in the mental lexicon, and inflected verbs share morphemic representations (such as roots, stems and suffixes) with all of the words from the same morphological family that have their own lexical entry representation.

## 4.5 Nature of the Representation

Studies conducted on Spanish have shown that word stress is defined by word structure, meaning that the morphemic nodes and the phonological characteristics of the merged morphemes are crucial for word stress (Oltra-Massuet and Arregi, 2005). The same analysis was conducted in Catalan (Oltra-Massuet, 1999), and similar assumptions were made by Andreassen and Eychenne (2013) in French (however, their argument was not deeply developed). Nevertheless, we suggest that word stress in French is strongly driven by word structure. In the case of verbs, word stress is defined by the tense and agreement nodes. The French iambic prosodic system is different from other Romance languages, which have a trochaic prosodic system. In this sense, it is the stressed syllable that defines the phonetic production in French phonological change verbs (Kilani-Schoch and Dressler, 2005; Aronoff, 2012). This means that the different phonetic stem productions of phonological change verbs are exclusively driven by prosodic rules, not by different morphological representations (Halle and Idsardi, 1996; Marslen-Wilson and Zhou, 1999; Embick, 2013). Accordingly to this assumption, our results showed that two phonetic alternation forms did not present any difference but activated a shared stem representation that is partly underspecified. Another possibility is that all morphemes are purely abstract and have no phonological content. Just after the morphemes are merged in the inflected word, the phonetic form is guided by phonological readjustment rules and is defined in a late insertion (Halle and Marantz, 1993; Embick and Halle, 2005; Marantz, 2013).

For idiosyncratic verbs, Meunier and Marslen-Wilson (2004) showed that different allomorphic stems have the same priming effects as fully regular verbs (e.g., *[boi]rons* ‘we will drink’ and *[buv]ons* ‘we drink’) when priming their infinitive form (*[boi]re*, ‘to drink’). Our results significantly extend this investigation and suggest that allomorphic stems have different representations in the mental lexicon. Thus, the priming effect observed may be due to links between the different representations, or accordingly to Crepaldi et al. (2010) to a shared underlined representation in the lemma level (Forster et al., 1987; Allen and Badecker, 2002). Our results show that idiosyncratic verbs are decomposed and recognised through the specific stem representations of a single verb in the mental lexicon (Aronoff, 2012). Idiosyncratic stem allomorphs are represented in the mental lexicon as different bound-morphemes but are linked at a common abstract morphological level (Aronoff, 1994; Wunderlich, 1996; Clahsen, 1999). Thus, the time spent to recover a specific stem allomorph is modulated as a function of its cumulative frequency.



## 5 Conclusion

The overall cumulative frequency effect is strong evidence that all inflected verbs in French are decomposed in visual modality independent of their stem regularity and phonological realisation. Consequently, the surface frequency effect is interpreted as the result of the recombination between the lexical information of the stem and the morphosyntactic features of the suffixes (Taft, 1979; 2004). Taken together, our results can be explained by either an obligatory decomposition model (Halle and Marantz, 1993; Taft, 2004; Marantz, 2013) or a revised dual-route model similar to the MM model (Wunderlich, 1996), which posits completely combinatorial and internally structured representations.

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## **Conflict of Interest Statement**

The authors declare that this research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

# Appendix A

## a. Fully-regular verbs

Word	C+	S+	Word	C+	S-	Word	C-	S+	Word	C-	S-
aimions	795.61	6.55	aimeront	795.61	0.34	figurez	57.23	6.15	figurera	57.23	0.34
avacent	195.00	7.50	avancera	195.00	0.74	brillant	81.22	7.50	brillais	81.22	0.14
cherchez	448.99	7.36	cherchez	448.99	0.74	baignait	41.42	6.62	baignons	41.42	0.14
donnerai	896.01	6.15	donneriez	896.01	0.34	reculons	69.05	6.62	reculera	69.05	0.14
entrent	398.38	7.30	entriez	398.38	0.20	détache	65.47	7.23	détachez	65.47	0.41
essayez	296.69	6.96	essayes	296.69	0.34	inspire	45.00	6.82	inspires	45.00	0.07
fermaient	197.16	5.27	fermera	197.16	0.34	utilisait	43.51	5.41	utilisons	43.51	0.07
frappent	168.31	5.34	frappons	168.31	0.00	tremblent	34.13	5.68	trembliez	34.13	0.00
gardais	257.50	5.74	garderas	257.50	0.61	discute	58.65	5.54	discutes	58.65	0.14
laisserai	851.55	5.81	laisseras	851.55	0.74	pardonnez	44.59	5.74	pardones	44.59	0.54
marchais	325.61	7.91	marcheras	325.61	0.27	insistait	67.03	7.97	insistons	67.03	0.20
occupent	219.80	7.30	occupez	219.80	0.07	habille	67.36	7.97	habiliez	67.36	0.20
oserait	155.54	5.34	oserons	155.54	0.00	agitent	89.19	5.54	agitera	89.19	0.07
oublierai	286.96	6.55	oubliez	286.96	0.07	accusait	39.93	6.55	accusons	39.93	0.14
pleurais	163.31	5.07	pleurera	163.31	0.61	désirais	61.89	4.66	désireras	61.89	0.07
refusais	152.77	4.59	refuseras	152.77	0.27	organise	47.90	4.19	organisez	47.90	0.07
regardes	997.91	5.34	regardiez	997.91	0.54	dépassent	78.78	5.74	dépassais	78.78	0.41
roulent	163.45	6.28	roulera	163.45	0.34	examine	50.68	6.28	examinez	50.68	0.07
serraient	207.50	5.81	serrerons	207.50	0.07	attaquait	70.41	6.01	attaquez	70.41	0.41
touchent	190.27	6.69	touchons	190.27	0.81	admirais	68.18	6.35	admirez	68.18	0.41



## b. Phonological change e/ɛ verbs with orthographic markers

Word	C+	S+	Word	C+	S-	Word	C-	S+	Word	C-	S-
achetaient	122.98	2.16	achetions	122.98	0.20	achèterai	25.42	2.3	achètera	25.42	0.74
achevait	66.06	12.64	achevais	66.06	0.54	achève	15.41	11.22	achèvera	15.41	0.27
amenez	73.79	1.28	amenais	73.79	0.34	amènerait	20.15	2.16	amèneras	20.15	0.07
appelez	295.00	11.42	appelez	295.00	0.07	appelles	170.33	8.72	appellerez	170.33	0.20
crevait	61.63	4.19	crevions	61.63	0.07	crèvent	19.94	5.47	crèvera	19.94	0.14
élevaient	79.22	4.73	élevais	79.22	0.61	élèvevent	24.68	5.27	élèvera	24.68	0.34
emmenez	77.97	2.77	emmeniez	77.97	0.14	emmènerai	27.52	2.64	emmènerez	27.52	0.41
enlevez	60.76	2.23	enlevais	60.76	0.14	enlèvent	18.05	1.55	enlèverai	18.05	0.27
feuilletait	17.84	2.91	feuilletez	17.84	0.07	feuillette	3.65	3.51	feuillettes	3.65	0,00
jetais	277.45	3.04	jetons	277.45	0.27	jetterait	59.41	2.50	jetterez	59.41	0.20
levons	347.84	1.49	leviez	347.84	0.07	lèvera	91.57	1.89	lèveras	91.57	0.07
menaient	102.18	6.96	menions	102.18	0.14	mènent	35.56	7.57	mèneras	35.56	0.14
pesaient	51.52	3.99	pesions	51.52	0.14	pèsent	19.40	4.32	pèsera	19.4	0.54
projetait	27.04	6.69	projetais	27.04	0.74	projette	5.75	4.73	projettes	5.75	0,00
ramenaient	83.83	3.72	rameniez	83.83	0,00	ramènerait	25.42	2.03	ramèneras	25.42	0.14
rappelez	128.06	8.04	rappelons	128.06	0.41	rappelles	75.22	8.38	rappellerez	75.22	0.14
rejetait	40.47	5.74	rejetez	40.47	0.07	rejette	6.09	5.34	rejettes	6.09	0,00
relevaient	101.01	3.51	relevais	101.01	0.20	relèvent	23.94	2.57	relèves	23.94	0.20
renouvelait	16.84	1.62	renouvelez	16.84	0,00	renouvelle	2.58	1.62	renouvelles	2.58	0,00
semait	22.45	1.49	semaient	22.45	0.54	sèment	2.99	1.89	sèmera	2.99	0,00

## c. Phonological change o/ɔ verbs without orthographic markers

Word	C+	S+	Word	C+	S-	Word	C-	S+	Word	C-	S-
accrochais	83.51	1.01	accrochiez	83.51	0,00	accrochent	3.26	2.64	accrochera	3.26	0.07
adorais	24.34	2.30	adoriez	24.34	0.07	adorent	20.29	2.91	adores	20.29	0.27
affolait	13.12	2.70	affoliez	13.12	0,00	affole	5.28	4.19	affolera	5.28	0.07
approchez	158.51	2.43	approchiez	158.51	0.07	approchent	37.64	4.93	approches	37.64	0.61
bloquait	19.26	2.03	bloquais	19.26	0.20	bloque	3.86	3.04	bloquent	3.86	0.54
collaient	90.08	3.78	collais	90.08	0.34	collent	17.11	2.97	collerez	17.11	0,00
dévorait	29.72	4.32	dévorons	29.72	0.14	dévore	7.92	4.86	dévores	7.92	0.07
envolait	22.49	2.16	envolons	22.49	0,00	envolent	7.39	2.30	envoles	7.39	0,00
étonnais	81.64	3.58	étonnons	81.64	0.20	étonnerait	34.96	7.84	étonnerai	34.96	0.07
évoquais	57.59	2.03	évoquez	57.59	0.07	évoquent	15.96	2.57	évoquerez	15.96	0,00
flottaient	47.24	6.62	flottions	47.24	0.14	flottent	16.70	5.34	flotteras	16.70	0,00
frottait	40.02	8.38	frottez	40.02	0,00	frotte	10.14	8.58	frottes	10.14	0.07
ignorons	105.88	1.28	ignoriez	105.88	0.61	ignore	2.57	1.42	ignorera	2.57	0.27
interrogeait	58.03	8.24	interrogeions	58.03	0.20	interroge	15,00	12.36	interroges	15,00	0.20
moquez	34.26	1.15	moquons	34.26	0.07	moquent	16.09	2.36	moquerez	16.09	0.07
nommait	50.76	6.82	nommais	50.76	0.27	nomment	11.57	1.22	nommes	11.57	0.07
rapprochait	42.52	7.57	rapprochais	42.52	0.27	rapproche	12.18	8.11	rapprochera	12.18	0.41
sonnent	68.67	3.85	sonnais	68.67	0.41	sonnerait	23.92	1.08	sonneras	23.92	0.07
téléphonez	50.63	1.69	téléphonais	50.63	0.34	téléphonerai	16.44	1.35	téléphonent	16.44	0.68
volaient	70.55	5.20	volons	106,00	0.20	volent	18.13	5.61	volerez	84,00	0.07

## d. Idiosyncratic verbs

Word	C+	S+	Word	C+	S-	Word	C-	S+	Word	C-	S-
apercevait	85.43	25.68	apercevrai	85.43	0.20	aperçoit	42.49	21.82	aperçoives	42.49	0.14
apprendra	107.50	5.07	apprendrez	107.50	0.74	apprenais	31.97	5.47	apprenons	31.97	0.68
boirai	148.18	1.55	boiras	148.18	0.74	buvions	54.12	2.36	buviez	54.12	0.14
connaissiez	335.26	2.84	connaisses	335.26	0.74	connaîtrait	160.28	2.77	connaîtrez	160.28	0.74
craignait	49.66	20.14	craignes	49.66	0.00	crains	38.18	17.64	craindra	38.18	0.07
devenais	376.50	6.15	deveniez	376.50	0.14	deviendrait	89.26	8.58	deviendras	89.26	0.95
envoyaient	131.57	2.91	envoyions	131.57	0.07	enverrai	10.27	2.70	enverras	10.27	0.47
mourait	169.60	11.35	mouriez	169.60	0.00	meurent	42.51	10.47	meures	42.51	0.14
obtenait	62.71	2.36	obtenons	62.71	0.41	obtient	7.31	3.18	obtiendra	7.31	0.41
parvenais	95.42	5.07	parveniez	95.42	0.07	parviens	7.31	5.88	parviendra	7.31	1.22
prévenait	58.46	2.23	prévenais	58.46	0.07	prévient	10.21	2.03	préviendra	10.21	0.2
recevaient	94.33	4.93	recevions	94.33	0.81	reçoivent	27.36	4.19	reçoives	27.36	0.00
rejoignent	40.97	5.07	rejoignais	40.97	0.34	rejoins	29.59	3.65	rejointes	29.59	0.54
reprends	114.73	7.16	reprentras	114.73	0.07	reprenaient	54.40	5.88	reprenions	54.40	0.68
retenait	103.52	15.34	retenions	103.52	0.34	retient	21.70	13.11	retiendra	21.70	0.54
revoyais	87.31	4.73	reverront	87.31	0.74	reverrai	18.51	4.05	revoyons	18.51	0.41
souvenaient	94.33	2.16	souvenions	94.33	0.27	souviens	6.69	3.38	souviennes	6.69	0.27
surprend	28.46	7.09	surprenons	28.46	0.14	surprenait	13.53	7.30	surprendra	13.53	0.61
tenions	525.82	4.80	teniez	525.82	0.95	tiendra	193.04	4.59	tiendrez	193.04	0.74
valaient	82.31	5.27	valais	82.31	0.47	vaille	5.54	5.34	vailent	5.54	0.21

## 3.2 Study 2: Stem Formation in French Verbs



# Stem Formation in French Verbs: Structure, Rules, and Allomorphy

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## Abstract

Stem processing is an essential phase in different models of word recognition. Most modern Romance languages, such as Catalan, Italian, Portuguese, Romanian, and Spanish, have three theme vowels that define verbal classes and stem formation. However, French verbal classes are not traditionally defined in terms of theme vowels. In this work, stem formation from theme vowel and allomorphic processes was investigated in French verbs. Our aim was to define the verbal stem formation structure processed during mental lexicon access in French. We conducted a cross-modal experiment and a masked priming experiment on four different French stem formation processes from the 1st and 3rd classes. We compared morphology-related priming effects to effects of full priming obtained through an identity priming condition as well as of no priming obtained with an unrelated control condition. Verbs from the 1st and 3rd classes with theme vowel stems presented full priming, whereas verbs from the 3rd class with allomorphic stems presented partial priming in both experiments. Partial priming was interpreted as reflecting processing of a different stem during lexical access. Our results suggest root-based stem formation for French. Verbs are recognized through word decomposition into stem and inflectional suffixes, while stem processing is based on decomposition into the root and theme vowel and allomorphic processes. These results are interpreted as supporting a single-mechanism model with full decomposition and lexical activation defined by morphological rules.

**Keywords:** Stem; Theme Vowel; Morphology; Inflection; Allomorphy; Rules; Structure; Processing; Representation; Priming.

# 1 Introduction

Morphology processing has received considerable attention in psycho-, neuro-, and linguistic research over the last four decades due to the strong symbolic manipulation assumptions that this level underlines (Amenta & Crepaldi, 2012; Clahsen, 2006b). The morphological level in word recognition is now better understood, but challenges in language idiosyncrasies and cross-linguistic comparisons remain. In this work, we investigated stem formation defined by theme vowel and allomorphic processes in French verbs. We explored the stem structure and morphological processing in verbal inflection through two priming experiments, one cross-modal and another masked, to better understand stem lexical access during word recognition. The following questions guided our investigation: a) How are stems from different micro-classes based on different types of stem formation processed? b) Is the identification of different French verbal forms explained by single- or dual-mechanism models? c) Are verbal forms pre- or post-lexically decomposed for lexical access?

## 1.1 Stems and Theme Vowel

Diachronically, Romance languages, such as Catalan, Italian, Portuguese, Romanian, and Spanish, inherited their verbal system from Latin, where we observe on the right side a tense node containing the tense (T) and agreement (Agr) inflectional suffixes and on the left side a stem (v) formed by the root ( $\sqrt{\text{ }}$ ) with semantic content and a theme vowel (Th) with a functional class distribution, yielding the general verbal hierarchical structure  $[[[\text{parl}]_{\sqrt{\text{ }}}[\text{e}]_{\text{Th}}]_{\text{v}}][[\text{r}]_{\text{T}}[\text{ont}]_{\text{Agr}}]_{\text{T}}]_{\text{TP}}$  *parleront* ‘they will speak’ (Arregi, 2000; Foley, 1979). Although the suffixal system is extremely regular and paradigmatic, stem formation presents specific rules and allomorphy, which are consistently affected by the Th and inflectional suffixes (M. I. Oltra-Massuet & Marantz, 1999). Synchronically, Romance languages reduced the four Latin Th to three (i.e., ‘a’, ‘e’, and ‘i’), as shown in Table 1. The Th is an empty morph without semantic content but with an exclusive functional role in verbal class distribution (Aronoff, 2012). However, the French verbal system presents many singularities

in stem formation and is not traditionally described in terms of Th (Kilani-Schoch & Dressler, 2005; but see Foley, 1979).

Language	ā	ě	ē	ī
<i>Latin</i>	<i>amāre</i>	<i>prendĕre</i>	<i>vidĕre</i>	<i>audīre</i>
Italian	amare	prendere	vedere	udire
Spanish	amar	prender	ver	oír
Portuguese	amar	prender	ver	ouvir
Catalan	amar	prendre	veure	sentir
<i>French</i>	<i>aimer</i>	<i>prendre</i>	<i>voir</i>	<i>ouïr</i>
Gloss (English)	‘to love’	‘to take’	‘to see’	‘to hear’

Table 1 – Stem and Th verbal classes in Romance languages. Infinitive forms.

French is traditionally defined as having three verbal classes: the 1st class with the [-er] ending is fully regular, is productive for new verbs (e.g., *googler* ‘to google’), and includes more than 8,500 verbs (Bescherelle, 2006). The 2nd class with the [-ir] ending with allomorphy in [-iss-] is fully regular, is not productive, and comprises approximately 250 verbs (Bonami et al., 2008). The 3rd class presents many micro-classes and specific stem formation processes, is not productive, and has approximately 350 verbs (Kilani-Schoch & Dressler, 2005). Compared to other Romance languages, French changed the ‘a’ to ‘e’ Th in the 1st class (but kept ‘a’ in obsolete tenses, such as in the indicative simple past and subjunctive imperfect past); in the 2nd class, French defined regular [-ir] endings, which were irregular verbs from the 4th class in Latin and 3rd class in other Romance languages; and in the 3rd class, French suppressed the short ‘ě’ Latin Th, establishing verbs without Th, changed the long ‘ē’ Th to ‘oi’, and developed many endings as a function of the ‘i’ Th (Foley, 1979).

In the present study, we tested different verbal micro-classes in French to examine whether different types of processing, as postulated by dual-mechanism models, are needed to handle their identification. Indeed, even if the 3rd class presents many different micro-classes (more than 25, see Kilani-Schoch & Dressler, 2005), from a cognitive perspective, it could



also be seen as a regular domain driven by combinatorial and allomorphic morphological rules for lexical access and word recognition (Gustavo Lopez Estivalet & Meunier, 2015a).

## 1.2 Inflectional Processing

Three families of morphological processing models have emerged since the 1970s: symbolic manipulation models, associative activation models, and dual-mechanism models. The first type argues that the mental lexicon contains morphological representations that are activated in word (de)composition, such as the Obligatory Decomposition (OD) model (Taft, 1979) and the Single Route (SR) model (Stockall & Marantz, 2006). The second type advocates that the mental lexicon is formed by associative whole word representations (Manelis & Tharp, 1977). In contrast, Parallel Distributed Processing (PDP) models compute different weights in the overlap of orthography, phonology, and semantics in hidden units (D. E. Rumelhart & McClelland, 1986). Alternatively, the amorphous Naïve Discriminative Learning (NDL) model predicts no activation of word structure and a direct form-to-meaning computation (Baayen et al., 2011).

Dual-mechanism models propose two routes for word recognition, a direct whole word route and another route operating through morphological decomposition; for example, the Augmented Addressed Morphology (AAM) model dissociates known and unknown words (Caramazza et al., 1988), the Parallel Dual-Route (PDR) model asserts a race between both routes (Baayen et al., 1997), and the Words and Rules (W&R) model differentiates regular and irregular words (Pinker, 1999). Alternatively, the Minimalist Morphology (MM) model proposes a route where irregular words are represented as sub-node lexical entries that contain variables (Wunderlich, 1996).

According to Marantz (2013, p.906), “the separationist understanding of morphemes allows for a complete integration of morphology with the syntax (the ‘grammar’ in everyday language) such that the internal structure of words finds analysis within the same syntactic architecture and subject to the same syntactic principles as the internal structure of phrases and sentences.” However, the morphological hierarchical structure of words has rarely been considered in psycho- and neuro-linguistic models of word processing and recognition, although it might have a role in word recognition. This implies that while a simple insertion rule such as *lire/lisons* ‘to read/we read’ may demand few resources, a complex substitution

rule such as *joindre/joignons* ‘to join/we join’ may demand greater resources, impacting the participant’s behavior.

Existing Romance language studies on the processing of different verbal classes have yielded contradictory results. Domínguez, Cuetos, and Segui (2000) propose that Spanish verbs from the 1st class are fully combinatorial whereas verbs from the 2nd and 3rd classes are lexically represented, according to the AAM model (but see Arregi, 2000; Bermúdez-Otero, 2013). A similar pattern of results has been observed in Catalan (Rodríguez-Fornells, Clahsen, Lleó, Zaake, & Münte, 2001, but see Oltra-Massuet & Marantz, 1999). Veríssimo and Clahsen (2009) argue that in Portuguese, although 1st class verbs are fully decomposed using a root-based mechanism, morphophonological 1st class verbs (e.g., *afogar/afogo* ‘to drown/I drown’) and 3rd class verbs are partially decomposed, having different stem representations in the mental lexicon, according to the MM model (but see Bassani & Lunguinho, 2011).

Italian presents more controversial results: Caramazza et al. (1988) argue in favor of the AAM, whereas Say and Clahsen (2002) propose that regular 1st class verbs are accessed through the combinatorial route and irregular 2nd and 3rd class verbs are accessed through the whole word route, according to the W&R. In contrast, Orsolini and Marslen-Wilson (1997) show that priming effects in regular and irregular verbs from the three classes do not differ, suggesting a single-mechanism model with decomposition.

In French, Meunier and Marslen-Wilson (2004) observe that different verb types, i.e., fully regular (e.g., *aimer/aimer* ‘we love/to love’), morphophonological (e.g., *jeter/jeter* ‘you throw/to throw’), sub-regular (e.g., *peindre/peindre* ‘they paint/to paint’), and idiosyncratic verbs (e.g., *vont/aller* ‘they go/to go’), may be decomposed for lexical access, suggesting that word recognition in French is morpheme based. Thus, even if stems present morphophonological or allomorphic process, the paradigmatic suffixal system seems to trigger decomposition between the stem and inflectional suffixes in all French verbs (Fabre et al., 2007). Bonami et al. (2008) shows the systematic regularity of 2nd class French verbs, which might indeed be considered fully regular because a) there are no morphophonological verbs in the 2nd class; b) there are no phonological/orthographic rules in the 2nd class, such as the <c/ç> and <g/ge> rules found in the 1st class (e.g., *placer/plaçons* ‘to place/we place’, *manger/mangeons* ‘to eat/we eat’); and c) the 2nd class ‘i’ Th was completely incorporated into all 2nd class roots, and all forms have been stabilized in either [ $\sqrt{i}$ ] before the boundary and consonant or [ $\sqrt{iss-}$ ] before vocalic suffixes (i.e., [ $\sqrt{i}$ ] → [ $\sqrt{iss-}$ ]/\_V).

The general picture drawn is that Romance languages, even if structurally close, seem different at the morphological processing level; therefore, cross-linguistic comparisons of morphological processing can provide descriptive information for a better understanding of morphological processing in word recognition (Clahsen, 2006b).

## 1.3 Stem Formation

We conducted a cross-modal experiment and a masked priming experiment with a visual lexical decision task to investigate how stem formation impacts processing of French verbs. Cross-modal priming elicits conscious processing, resulting in lexical core activation through different modalities; however, it captures semantic and orthographic effects, which are undesired in our investigation (Allen & Badecker, 2002; Meunier & Marslen-Wilson, 2004). In contrast, visual masked priming relies on unconscious and automatic effects, providing evidence for rapid and early processes in word recognition (Kenneth I Forster & Davis, 1984). We used a 52 ms masked prime presentation in our experiment to track morphological processing. At this duration, orthographic overlap produces inhibition, and semantic activation is not measurable; thus, priming facilitation can be interpreted as morphological rather than in terms of orthographic overlap or semantic relatedness (Kenneth I. Forster, 1998; Longtin & Meunier, 2005).

We tested four different verb types that present specific stem formation processes (one from the 1st class and three from the 3rd class) and that are considered higher subdivisions in the verbal classes that assemble individual micro-classes. They represent 92.19% of the total verbs in French, and the three 3rd class verb types tested represent 84.24% of the total 3rd class verbs, also representative of different stem formation processes. The first verb type are fully regular verbs from the 1st class in [-er] (e.g., *parler/parlons* ‘to speak/we speak’); the second are regular verbs from the 3rd class in [-ir] (e.g., *sentir/sentons* ‘to feel/we feel’); the third are verbs from the 3rd class in [-ire] with allomorphic insertion (e.g., *lire/lisons* ‘to read/we read’); and the fourth are verbs from the 3rd class in [-indre] with allomorphic substitution (e.g., *joindre/joignons* ‘to join/we join’) (Bescherelle, 2006; Foley, 1979; Kilani-Schoch & Dressler, 2005).

We tested three different priming conditions (i.e., control, identity, and test). The identity priming condition is considered to reflect full priming, and the unrelated control priming condition reflects no priming; thus, the test priming condition was compared to these

two conditions. On the one hand, full priming in the test condition indicates that words are fully decomposed into atomic units and that even the stem is parsed into root and Th, indicating that stem formation is root based; on the other hand, no priming in the test condition implies that words are not decomposed, and the result favors whole word representation. Partial priming may indicate that different, albeit linked, allomorphic stem representations are activated in the prime and target pair (Amenta & Crepaldi, 2012; Clahsen, 1999; Kenneth I. Forster, 1998; Rastle & Davis, 2008; Say & Clahsen, 2002; Veríssimo & Clahsen, 2009).

Our hypothesis is that all French verbs from the different micro-classes are morphologically decomposed for lexical access and word recognition; therefore, the morphemic representations are processed in the mental lexicon through hierarchical structures, where the stem is processed by means of morphological and phonological rules (Halle & Marantz, 1993). The alternative hypothesis is that only the 1st class is root based and fully decomposed for lexical access, whereas the other classes are word based or stem based, accessed by whole word entries or sub-structured forms (Baayen et al., 1997; Caramazza et al., 1988; Pinker, 1999; Wunderlich, 1996).

## 2 Method

### 2.1 Experiment 1: Cross-Modal Priming

#### 2.1.1 Participants

A total of 48 adult native speakers of French between the ages of 18 and 29 (mean age 21.2, 25 women) participated in Experiment 1. All participants were right-handed, had normal hearing, had normal or corrected-to-normal vision, and had no history of cognitive and neurological disorders. All participants were undergraduate students at the *Université Lumière Lyon 2*. Participants did not know the purpose of the study and gave their written consent to participate in the experiment as volunteers. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the ethics committee *Comité de Protection des Personnes Sud-Est II* (IRB: 00009118).

## 2.1.2 Material and Design

The participants took part in a cross-modal priming experiment with auditory priming and a lexical decision task with visual targets. All words were chosen from the French database *Lexique* (New, Pallier, Brysbaert, & Ferrand, 2004). A total of 84 experimental pairs of verbs in four different verb types were selected, with 21 pairs for each verb type. The four verb types investigated were a) 1st class fully regular verbs in [-er]; b) 3rd class regular verbs in [-ir]; c) 3rd class allomorphic insertion verbs in [-ire]; and d) 3rd class allomorphic substitution verbs in [-indre].

We manipulated three different priming conditions: 1) control (e.g., *aimer/parlons* ‘to love/we speak’), 2) identity (e.g., *parlons/parlons* ‘we speak/we speak’), and 3) test (e.g., *parler/parlons* ‘to speak/we speak’). The experimental targets and identity priming condition were French verbs inflected in the indicative present tense and 1st person plural agreement formed by the root and the agreement suffix (i.e.,  $[[[\alpha]_V][[ons]_{Agr}]_T]_{TP}$ ); these forms were chosen because they have no Th. The control priming condition was a verb unrelated to the target but from the same verb type in the infinitive form. The test priming condition was the same verb as the target but in the morphology-related infinitive form, which presents the Th. Examples of all experimental conditions are shown in Table 2.

Verb Type	Control	Test	Identity	Target
a) 1st class [-er]	aimer	parler	parlons	PARLONS
b) 3rd class [-ir]	dormir	sentir	sentons	SENTONS
c) 3rd class [-ire]	écrire	lire	lisons	LISONS
d) 3rd class [-indre]	feindre	joindre	joignons	JOIGNONS

Table 2 – Examples of experimental stimuli by verb types and priming conditions investigated in Experiments 1 and 2.

All experimental words were matched by orthographic lemma frequency, surface frequency, number of letters, number of phonemes, number of syllables, and OLD20 (Yarkoni, Balota, & Yap, 2008), as shown in Appendix A. A set of 196 filler pairs was added to the 84 experimental items, resulting in an experiment with a total of 280 stimuli, 30% of which were experimental pairs. In these 196 filler pairs, there were 84 phonologically related

word-pseudoword pairs and 56 unrelated word-pseudoword pairs, producing a total of 140 pairs with a pseudoword target for the non-existent word response. Another 56 unrelated word-word pairs were added to the experiment, producing a total of 140 pairs with a real word in the target, accounting for 50% of the pseudoword targets and 50% of the real word targets, as well as 50% of related pairs and 50% of unrelated pairs. The pseudowords were constructed by changing one or two letter positions using the toolbox available in the French database *Lexique* (New et al., 2004). Three different lists were constructed to counterbalance each target with the different priming conditions in a pseudorandom order using the Mix software (van Casteren & Davis, 2006). All words used in Experiment 1 were recorded by a 22-year-old female native speaker of French.

### 2.1.3 Procedure

The participants were tested individually in a quiet room in the *Université Lumière Lyon 2*. We used E-Prime® 2.0 Professional (Psychology Software Tools, Inc., Sharpsburg, PA, USA) for experimental construction, stimuli presentation, and data collection. Each trial followed this sequence: first, a fixation point was displayed on the center of the screen for 500 ms; second, an auditory prime was played; and third, immediately after the priming offset, the visual target was displayed on the center of a 15" LCD screen in uppercase 20 point Courier New font in white letters against a black background. The measurement of reaction time (RT) started with the onset of the target presentation, which remained on the screen for 2,000 ms or until the participant's response. After the target disappeared, there was an inter-stimuli blank screen for 500 ms, and the next trial then started with the presentation of the fixation point. The participants were asked to perform a lexical decision task on visual targets as quickly and accurately as possible using both hands on a computer keyboard, where the right hand over the 'green' button corresponded to real words and the left hand over the 'red' button corresponded to pseudowords. The entire experiment lasted approximately 24 minutes.

### 2.1.4 Results of Experiment 1

Only the experimental targets were analyzed. To avoid extreme fast and slow responses, RTs below 300 ms and above 1,800 ms were removed from the data (.84%). Two targets (i.e., *CEIGNONS* 'we surround' and *DEPARTONS* 'to depart') had error rates higher than 50% and

were discarded (2.33%); incorrect responses were removed for the RT analysis (6.25%). In total, 9.20% of the experimental stimuli were removed. The overall RT means, standard deviations (SDs), priming differences, significant differences, and error rates are shown in Table 3.

Verb Type	Control	Test	Identity	C-T	T-I	Error(%)
a) 1st class [-er]	723(211)	637(168)	624(173)	86***	13	.85
b) 3rd class [-ir]	752(202)	659(190)	652(201)	93***	7	2.25
c) 3rd class [-ire]	701(192)	645(178)	621(178)	56***	24***	1.10
d) 3rd class [-indre]	778(249)	711(209)	676(216)	67***	35***	2.05

\*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$

Table 3 – Experiment 1: RT means, SDs between parentheses, priming differences, significant differences, and error rates by verb type and priming condition. C-T represents control minus test, and T-I represents test minus identity.

RTs were normalized (i.e.,  $1/RT * -1000$ ) and analyzed by means of a mixed-effects model (Baayen, 2008), with the transformed RTs as the dependent variable, participants and targets as random variables, and verb type and priming condition as fixed-effect variables. All analyses were performed with R software version 3.1.2 (R Foundation for Statistical Computing, Vienna, Austria), including ‘lme4’, ‘lmerTest’, and ‘car’ packages.

The main results through an analysis of variance (ANOVA) of type III with Satterthwaite approximation for degrees of freedom show a significant effect of verb type ( $F(3,77) = 4.983, p < .01$ ), and a significant effect of priming condition ( $F(2,3529) = 165.804, p < .001$ ), but no significant interaction between these two variables ( $F(6,3529) = 1.478, p = .182$ ). Following our hypothesis, we analyzed the planned comparisons of the priming effects by verb type: a) 1st class verbs in [-er] present a significant difference between the control and test conditions ( $t(3526) = 7.284, p < .001$ ), and no difference between the test and identity conditions ( $t(3525) = -1.193, p = .128$ ), indicating that the targets are fully primed. b) 3rd class verbs in [-ir] also show a significant difference between the control and test conditions ( $t(3539) = 8.068, p < .001$ ), and no difference between the test and identity conditions ( $t(3526) = -1.131, p = .258$ ), suggesting again that the targets are fully primed. In contrast,

c) 3rd class verbs in [-ire] present a significant difference between the control and test conditions ( $t(3529) = 5.622, p < .001$ ), and a significant difference between the test and identity conditions ( $t(3526) = -3.615, p < .001$ ), suggesting that the test condition behaves differently from the control and identity conditions, reaching partial priming. Similarly, d) 3rd class verbs in [-indre] show a significant difference between the control and test conditions ( $t(3530) = 4.466, p < .001$ ), and a significant difference between the test and identity conditions ( $t(3528) = -3.539, p < .001$ ), also suggesting partial priming.

The error rates for the priming conditions were control 3.71%, identity 1.36%, and test 1.18%. Error rates were analyzed by means of a generalized mixed-effects model (Baayen, 2008), with the logit accuracy (ACC) as the dependent variable, participants and targets as random variables, verb type and priming condition as fixed-effect variables, and the binomial family specified in the model. The analysis of deviance of type II Wald chi-square test shows a significant effect of verb type ( $\chi^2(3, N = 48) = 8.174, p < .05$ ), and a significant effect of priming condition ( $\chi^2(2, N = 48) = 81.533, p < .001$ ), but no significant interaction between these two variables ( $\chi^2(6, N = 48) = 10.495, p = .105$ ).

### 2.1.5 Discussion of Experiment 1

Overall, we observed an effect of morphology-related priming in RTs and error rates. More specifically, we found full priming in the two verb types in which the stem is formed by the combination of root and Th: a) 1st class fully regular verbs in [-er] and b) 3rd class regular verbs in [-ir]. We found partial priming in the two other verb types in which the stem is formed by allomorphic processes: c) 3rd class allomorphic insertion verbs in [-ire] and d) 3rd class allomorphic substitution verbs in [-indre].

The full priming effect reveals similarity between the morphology-related and identity priming conditions, thus suggesting the same facilitation between the identity priming stem without the Th and the test priming stem with the Th. Associated with significant differences between morphology-related test and control priming conditions, this result suggests full decomposition of the word and activation of the same morphemes in the prime and target stimuli (Amenta & Crepaldi, 2012). Therefore, it seems that the 1st class fully regular verbs in [-er] and the 3rd class regular verbs in [-ir] were fully decomposed for lexical access and that their morphemic constituents were activated, including the root (as the prime and the target have different stems) (Say & Clahsen, 2002; Veríssimo & Clahsen, 2009).



In contrast, the partial priming results in the 3rd class insertion verbs in [-ire] and the 3rd class substitution verbs in [-indre] suggest different, albeit linked, stem representations activated during the prime and target stimuli rules (e.g., [-ire]: [*li*]re/[*lis*]ons ‘to read/we read’, [-indre]: [*joind*]re/[*joign*]ons ‘to join/we join’) (Allen & Badecker, 2002). Alternatively, these results can be explained in light of stem allomorphic rules; in the former, there is a linking consonant insertion into the stem, and in the latter, there is a morphemic substitution in the stem for the merge with the inflectional suffixes (M. I. Oltra-Massuet & Marantz, 1999). We note that these different stem formation processes seem to be triggered by a formal morphophonological rearrangement in the stem, which is merged with the regular and systematic inflectional suffixes (Fabre et al., 2007).

These results are different from those obtained for Catalan (Rodríguez-Fornells et al., 2001), Italian (Say & Clahsen, 2002), Portuguese (Veríssimo & Clahsen, 2009), and Spanish (Domínguez et al., 2000), where results showed full priming only in the 1st class but partial priming in the other classes (but see Orsolini & Marslen-Wilson, 1997). Considering the major concerns in cross-modal priming in relation to orthographic, phonological, and semantic effects, we conducted a masked priming experiment with the same linguistic material (Kenneth I Forster & Davis, 1984; Kenneth I. Forster, 1998).

## 2.2 Experiment 2: Masked Priming

### 2.2.1 Participants

A total of 48 adult native speakers of French between the ages of 18 and 31 (mean age: 22.81, 26 women) participated in Experiment 2; no participants took part in both Experiments 1 and 2. The participants had the same characteristics as described in Experiment 1. Participants did not know the purpose of the study and gave their written consent to participate in the experiment as volunteers. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the ethics committee *Comité de Protection des Personnes Sud-Est II* (IRB: 00009118).

### 2.2.2 Material and Design

The participants performed a masked priming experiment with a lexical decision task on visual modality using the same material from Experiment 1; additionally, we included a set of

stimuli e) control [orth/sem] to control any orthographic and semantic priming effects (Kenneth I. Forster, 1998; Meunier & Marslen-Wilson, 2004). The e) control [orth/sem] set of stimuli consisted of 21 pairs of words where the targets had the same characteristics as all the other targets. We then manipulated the following three particular priming conditions: 1) control (e.g., *réfugier/admirons* ‘to refuge/we admire’), 2) orthographic (e.g., *administrer/admirons* ‘to administer/we admire’), and 3) semantic (e.g., *apprécier/admirons* ‘to appreciate/we admire’). The control priming condition was a completely different verb, the orthographic priming condition was a verb that was only orthographically related to the target, and the semantic priming condition was a different verb but was semantically related to the target. The e) control [orth/sem] set of stimuli was controlled and matched according to the same lexical characteristics as the other verb types, as shown in Appendix B. The complete list of experimental stimuli is shown in Appendix C.

### 2.2.3 Procedure

The participants were tested individually in a quiet room in the *Université Lumière Lyon 2*. We used the same general procedure as described in Experiment 1. However, in Experiment 2, the primes were presented visually in lowercase for 52 ms and were preceded by a mask of hash marks for 500 ms. Therefore, each trial followed this sequence: first, a fixation point was displayed on the center of the screen for 500 ms; second, a visual mask with 10 hash marks (largest word) was displayed on the center of the screen for 500 ms; third, immediately after the mask offset, the visual prime was displayed in lowercase for 52 ms; and, fourth, immediately after the prime offset, the visual target was displayed on the center of the screen in uppercase for 2,000 ms or until the participant’s response. The entire experiment lasted approximately 20 minutes.

### 2.2.4 Results of Experiment 2

Only the experimental targets were analyzed. RTs below 300 ms and above 1,800 ms were removed from the data to avoid extremely fast and slow responses (.56%); one target (i.e., *CEIGNONS* ‘we surround’) had an error rate higher than 50% and was discarded (.96%); incorrect responses were removed for the RT analysis (7.29%). In total, 8.69% of the experimental stimuli were removed. The overall RT means, SDs, priming differences, significant differences, and error rates are shown in Table 4.

Verb Type	Control	Test	Identity	C-T	T-I	Error(%)
a) 1st class [-er]	698(177)	671(180)	665(173)	27*	6	.76
b) 3rd class [-ir]	740(223)	683(197)	691(216)	57***	-9	2.22
c) 3rd class [-ire]	686(177)	664(166)	656(200)	22*	18*	.77
d) 3rd class [-indre]	810(255)	742(236)	687(212)	68***	55***	1.97
e) Control [orth/sem]	707(202)	701(184)a	705(209)b	6	-4	1.57

\*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$

a The test priming condition must be replaced by the semantic priming condition.

b The identity priming condition must be replaced by the orthographic priming condition.

Table 4 – Experiment 2: RT means, SDs between parentheses, priming differences, significant differences, and error rates by verb type and priming condition. C-T represents control minus test, and T-I represents test minus identity.

The analyses were performed as in Experiment 1. The ANOVA in the RT mixed-effects model showed a significant effect of verb type ( $F(4,97) = 3.108, p < .05$ ), a significant effect of priming condition ( $F(2,4443) = 51.054, p < .001$ ), and a significant interaction between these two variables ( $F(8,4443) = 4.929, p < .001$ ). Proceeding the planned comparisons in the priming condition, a) 1st class verbs in [-er] present a significant difference between the control and test conditions ( $t(4443) = 2.286, p < .05$ ), and no difference between the test and identity conditions ( $t(4442) = -1.191, p = .234$ ), indicating that the targets are fully primed. The same holds for b) 3rd class verbs in [-ir], a significant difference between the control and test conditions ( $t(4442) = 5.112, p < .001$ ), and no difference between the test and identity conditions ( $t(4446) = .118, p = .906$ ), indicating that the targets from the 1st and 3rd classes are fully primed. In contrast, c) 3rd class verbs in [-ire] presented a significant difference between the control and test conditions ( $t(4444) = 2.204, p < .05$ ), and a significant difference between the test and identity conditions ( $t(4443) = -1.971, p < .05$ ), suggesting that the test condition behaves differently from the control and identity conditions, reaching partial priming. A similar pattern is observed for d) 3rd class verbs in [-indre], with a significant difference between the control and test conditions ( $t(4443) = 4.553, p < .001$ ), and a significant difference between the test and identity conditions ( $t(4445) = -4.066, p < .001$ ), also indicating partial priming of the target. Finally, e) control [orth/sem] does not present any difference between the control and semantic conditions ( $t(4446) = -.441, p = .659$ ), or

between the control and orthographic conditions ( $t(4442) = -.826, p = .409$ ), suggesting that the semantic and orthographic conditions do not facilitate RTs in target recognition in masked priming.

It becomes clear that the interaction between verb type and priming condition is only significant in the masked priming experiment because of the e) control [orth/sem] results. An alternative mixed-effects model without this e) control [orth/sem] condition reveals no significant interaction between verb type and priming condition ( $F(6,3546) = 1.776, p = .194$ ).

The error rates for the priming conditions were as follows: control 2.87%, identity 2.24%, and test 2.18%. The error rates were analyzed as in Experiment 1. The main results showed a significant effect of verb type ( $\chi^2(4, N = 48) = 10.459, p < .05$ ), and a significant effect of priming condition ( $\chi^2(2, N = 48) = 7.627, p < .05$ ), but no significant interaction between these two variables ( $\chi^2(8, N = 48) = 11.092, p = .196$ ).

## 2.2.5 Discussion of Experiment 2

The masked priming experiment showed a pattern of results similar to that of the cross-modal one. Overall, a morphology-related priming effect is observed in RTs and error analyses. We observed full priming for the a) 1st class fully regular verbs in [-er] and the b) 3rd class regular verbs in [-ir], and partial priming for the c) 3rd class allomorphic insertion verbs in [-ire] and the d) 3rd class allomorphic substitution verbs in [-indre].

In line with previous masked priming experiments, there was no significant priming effect in the e) control [orth/sem] set of stimuli. Thus, the results reject any evidence of facilitation between the prime and target mediated by semantic relations or orthographic overlap (Crepaldi et al., 2010; Kenneth I Forster & Davis, 1984; Kenneth I. Forster, 1998; Longtin & Meunier, 2005).

# 3 General discussion

## 3.1 Morphology as a Complex Domain

Morphological processing has been a challenging domain in psycho-, neuro-, and linguistic research, yielding contradictory results and the development of different theoretical

and psycholinguistic models (Amenta & Crepaldi, 2012; Clahsen, 2006b). In this work, we investigated the morphological processing of French stem formation through root and Th combinations and allomorphic rules in four different French verb types using two experimental paradigms: cross-modal priming and masked priming. The RT results in both experiments revealed a full priming effect for verbs with the 1st and 3rd classes stems formed by the combination of root and Th: a) 1st class fully regular verbs in [-er] and b) 3rd class regular verbs in [-ir]. In contrast, the results showed a partial priming effect for verbs with the 3rd class stems formed by allomorphic rules: c) 3rd class allomorphic insertion verbs in [-ire] and d) 3rd class allomorphic substitution verbs in [-indre].

These results are in line with those of Meunier and Marslen-Wilson (2004), who showed that fully regular, morphophonological, sub-regular, and idiosyncratic French verbs have similar behaviors, and their access should not be based on dual-mechanism models. The present work extended this investigation to specific stem formation processes driven by root and Th combination, allomorphic insertion, and allomorphic substitution rules. In contrast to other Romance language studies that found full priming only in the 1st class and partial priming in the other classes (Bermúdez-Otero, 2013; Domínguez et al., 2000; Say & Clahsen, 2002; Veríssimo & Clahsen, 2009), postulating dual-mechanism models or stem based representations, our results showed that in the 1st and 3rd French verbal classes, target stems that do not contain a Th are equally primed by an identity prime, and a test prime in which the stem contain a Th (Orsolini & Marslen-Wilson, 1997).

Therefore, we consider our first question: a) How are stems from different micro-classes based on different types of stem formation processed? Our results showed differences in priming effects depending on stem formation with root and Th combination in the 1st class verbs in [-er] and the 3rd class verbs in [-ir] on one side, and allomorphic processes in the 3rd class verbs in [-ire] and the 3rd class verbs in [-indre] on the other side. We observed full priming for verbs that have stems formed by a root and Th combination, but the Th is not present when the stem is merged with vocalic inflectional suffixes (e.g., *parler/parlons* ‘to speak/we speak’, *dormir/dormons* ‘to sleep/we sleep’,  $[[\sqrt{v}][Th]v] \rightarrow [[\sqrt{v}]/\_V]$ ). We observed partial priming for verbs that do not have Th but that contain allomorphic stems according to the suffix with which the stem is merged, implying that these verbs may have different but linked stem representations activated in the prime and target or that they have abstract representations processed by morphological rules. For example, the 3rd class allomorphic insertion verbs in [-ire] would have a simple linking consonant insertion into the allomorphic stem that merges with pronounced suffixes (e.g., *disons* ‘we say’, *écrivons* ‘we write’;  $[\sqrt{v}] \rightarrow$

[ $\sqrt{\text{is}}|\sqrt{\text{iv}}/_\text{V}$ ), while the 3rd class allomorphic substitution verbs in [-indre] would have to be computed by a more complex rule (David Embick & Halle, 2005; Stockall & Marantz, 2006).

These assumptions and results imply that all French inflected verbs composed of different morphemes seem to be decomposed in their morphemic constituents to be accessed; while forms that have a Th can be stripped and can yield full priming, forms that have allomorphic stems do not have exactly the same morphemic representations activated and yield partial priming.

### 3.2 Stem, Allomorphy, and Rules

We then consider our second question: b) Is the identification of different French verbal forms explained by single- or dual-mechanism models? The full priming effect between the stem primes with and without Th and targets without Th in verbs from the 1st class in [-er] and 3rd class in [-ir] (e.g.,  $[[\text{parl}]e]r/[\text{parl}]ons$  ‘to speak/we speak’,  $[[\text{dorm}]i]r/[\text{dorm}]ons$  ‘to sleep/we sleep’) suggests that the stems containing the Th were fully decomposed into root and Th and that they activated the same morphemic representation, resulting in equal facilitation relative to that observed in the identity priming condition. The allomorphic 3rd class verbs in [-ire] and 3rd class verbs in [-indre] presented partial priming, suggesting that irregular French verbs from the 3rd class have different albeit linked allomorphic stem representations (Aronoff, 2012) or abstract root representations driven by allomorphic rules (Halle & Marantz, 1993).

Therefore, these results do not require postulating a dual-mechanism model with different routes to process Th and allomorphic stem formations. We argue that a single-mechanism model with morphological decomposition for lexical access can handle these results. This single-mechanism model might have atomic morphemic representations in the mental lexicon for all verb types, i.e.,  $[\text{parl}]er$  ‘to speak’,  $[\text{dorm}]ir$  ‘to sleep’,  $[\text{écri}]re$  ‘to write’,  $[\text{joind}]re$  ‘to join’; thus, the former two verb types present full decomposition with simple Th stripping for lemma activation. The latter two verb types also present full decomposition, resulting in different atomic allomorphic stems between the prime and target. The partial priming result observed reflects the activation of these different allomorphic stem representations or the computation of allomorphic rules with different degrees of complexity to transform one form into the other for lemma activation (Gustavo Lopez Estivalet &

Meunier, 2015a; Meunier & Marslen-Wilson, 2004; Orsolini & Marslen-Wilson, 1997; Stockall & Marantz, 2006; Taft, 1979).

We then review our third question: c) Are verbal forms pre- or post-lexically decomposed for lexical access? Our results from the masked priming experiment are in line with previous results on the effects of morphology-related priming. The full priming results from the 1st class fully regular verbs in [-er] and the 3rd class regular verbs in [-ir] can be compared to those of studies that concluded a, early full decompositional mechanism for the 1st class (Domínguez et al., 2000; Rodríguez-Fornells et al., 2001; Say & Clahsen, 2002; Veríssimo & Clahsen, 2009) or for regular verbs (Baayen et al., 1997; Clahsen, 1999; Pinker, 1999). These verbs seem to undergo full decomposition that occurs pre-lexically and is used for lexical access and word recognition (Amenta & Crepaldi, 2012; Clahsen, 1999; Kenneth I Forster & Davis, 1984; Kenneth I. Forster, 1998; Rastle & Davis, 2008; Say & Clahsen, 2002; Veríssimo & Clahsen, 2009), presenting the same verbal hierarchical structure and morphological nodes. They are decomposed early into the stem (lexical morpheme) and inflectional suffixes (functional morphemes) for morphosyntactic feature processing, and the stem is decomposed later into the root and Th for semantic feature processing (David Embick & Halle, 2005). We note that in French verbal forms that have the stem directly combined with a pronounced agreement suffix, regular stems do not have the Th, and irregular stems present an allomorphic form (Foley, 1979). Thus, the wide consistency between morphemes in the verbal hierarchical structure and the systematic stem formation processes with Th or allomorphic rules ensures the full decomposition of inflected verbs into atomic morphemic representations (Marantz, 2013b).

Concerning the partial priming results in the 3rd class allomorphic insertion verbs in [-ire] and in the 3rd class allomorphic substitution verbs in [-indre], it can be argued that these micro-classes have linked allomorphic stem representations in the mental lexicon (Clahsen, 1999; Veríssimo & Clahsen, 2009). Alternatively, we suggest that they could have abstract root representations in the mental lexicon that are morphologically computed through allomorphic rules for lexical access and word recognition (Halle & Marantz, 1993; Stockall & Marantz, 2006). In the former interpretation, allomorphic stems have different representations in the mental lexicon that are activated according to the morphological context; these representations are linked in a complementary manner where each form is combined only with specific morphs and inflectional suffixes. This stem allomorphic representation hypothesis is in line with the two-level model proposed in Allen and Badecker (2002) and further developed in Crepaldi et al. (2010), where sensorial stimuli activate lexeme

representations at the first level and these lexemes further activate abstract lemma representations at the second level (e.g., Stimulus: *joindre/joignons* ‘to join/we join’; Lexeme: *[joind-]/[joign-]*; Lemma: JOINDRE).

In the second interpretation, roots are abstractly represented in the mental lexicon, and the morphological and phonological constraints trigger specific allomorphic rules in the roots to rearrange this morpheme to morphological merge between the stem and inflectional suffixes. Further experiments are needed to determine which interpretation is correct. This second hypothesis is in line with Stockall and Marantz, (2006), considering abstract root representations in the mental lexicon that are subject to core morphological and phonological rules for lexical access (e.g., Stimulus: *joindre/joignons* ‘to join/we join’; Stem: *[joind-]/[joign-]*; M-rule:  $[\sqrt{\text{ind-}}] \rightarrow [\sqrt{\text{ign-}}] / \_[\dots]_{\text{pronounced}}$ , P-rule:  $/\sqrt{\text{ẽd}}/ \rightarrow / \sqrt{\text{p}}/ / \_V$ ; Lemma: JOINDRE).

Independently of the hypothesis adopted, the results from both experiments support a root-based system for French verbal processing, with the inflected verbs decomposed into stem and inflectional suffixes and the stem decomposed into root and Th, if available, or allomorphic rules for lexical access. Finally, the implication is that because all verbal forms are fully decomposed into atomic units for lexical access, we should consider that the mental lexicon of French can be composed of morphemic representations that are hierarchically structured and processed in a symbolically computational and combinatorial manner (David Embick & Halle, 2005; Foley, 1979; Marantz, 2013b; M. I. Oltra-Massuet & Marantz, 1999; Taft, 1979).

## 4 Conclusion

Unlike experimental studies of other Romance languages, we showed that French verbs from the 1st and 3rd classes can be accounted by a single-mechanism model with morphological processing for lexical access (Gustavo Lopez Estivalet & Meunier, 2015a; Meunier & Marslen-Wilson, 2004; Orsolini & Marslen-Wilson, 1997; Stockall & Marantz, 2006; Taft, 1979). Our results suggest root-based processing for lexical access and word recognition. We propose that French inflected verbs are first decomposed into the stem and inflectional suffixes and later the stem is then processed at the lexeme level for subsequent lemma activation (Allen & Badecker, 2002). Finally, we showed that stem formation is strongly driven by morphological rules and allomorphic processes.



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## Appendix A

Verb Type	Priming	flemma	fsurf	letters	phon	syll	hom	OLD20
a) 1st class [-er]	Control	47.98	11.29	8.14	6.19	2.86	1.05	1.86
	Test	48.03	11.27	8.10	6.29	3.00	1.05	1.82
	Target	48.03	0.20	9.10	6.29	3.00	1.10	2.26
b) 3rd class [-ir]	Control	47.59	11.08	7.52	6.57	2.67	1.00	2.26
	Test	47.62	11.13	8.05	6.62	2.67	1.00	1.90
	Target	47.62	0.21	9.05	5.62	2.67	1.10	2.01
c) 3rd class [-ire]	Control	47.51	11.57	8.33	6.43	2.29	1.00	2.25
	Test	47.47	12.03	7.14	5.81	1.86	1.05	1.85
	Target	47.47	0.08	9.14	6.81	2.86	1.00	2.11
d) 3rd class [-indre]	Control	46.86	10.48	8.19	6.24	2.00	1.00	2.22
	Test	46.77	10.38	8.33	5.33	1.57	1.05	2.16
	Target	46.77	0.18	9.33	5.67	2.57	1.05	2.07

Appendix A - Means of each verb type and priming condition. flemma: lemma frequency, fsurf: surface frequency, letters: number of letters, phon: number of phonemes, syll: number of syllables, hom: number of homographs, and OLD20: Orthographic Levenshtein Distance.

## Appendix B

Verb Type	Priming	flemma	fsurf	letters	phon	syll	hom	OLD20
e) [orth/sem]	Control	47.03	11.46	7.90	6.19	2.43	1.10	1.98
	Semantic	46.30	10.71	7.90	6.24	3.00	1.00	1.96
	Ortho	49.75	12.49	7.86	5.86	2.67	1.05	2.11
	Target	49.08	0.37	8.90	6.00	2.62	1.00	2.24

Appendix B - Means of the e) control [orth/sem] verb type by priming condition in experiment 2 added to the complete material presented in Appendix A.

## Appendix C

a) 1st class [-er]			b) 3rd class [-ir]		
Target	Test	Control	Target	Test	Control
accrochons	accrocher	commander	accueillons	accueillir	frémir
alignons	aligner	estimer	bouillons	bouillir	maigrir
aventurons	aventurer	identifier	consentons	consentir	embellir
consultons	consulter	associer	cueillons	cueillir	pétrir
coupons	couper	glisser	défaillons	défaillir	rebondir
débutons	débuter	suspecter	démentons	démentir	surenchérir
détaillons	détailler	pratiquer	départons	départir	resplendir
dictons	dicter	notifier	desservons	desservir	subvertir
divisons	diviser	confronter	dévêtons	dévêtir	encourir
emportons	emporter	résister	endormons	endormir	choisir
facilitons	faciliter	informer	mentons	mentir	subir
félicitons	féliciter	contrôler	offrons	offrir	ravir
inventons	inventer	souffler	pressentons	pressentir	férir
présentons	présenter	chanter	recouvrons	recouvrir	accourir
préservons	préserver	indiquer	recueillons	recueillir	désobéir
réparons	réparer	exposer	repartons	repartir	maintenir
signons	signer	protester	ressentons	ressentir	ouvrir
simplifions	simplifier	diluer	revêtons	revêtir	subvenir
sollicitons	solliciter	lamenter	rouvrons	rouvrir	enquérir
supposons	supposer	attacher	souffrons	souffrir	réfléchir
tremblons	trembler	attaquer	vêtons	vêtir	languir

c) 3rd class [-ire]			d) 3rd class [-indre]		
Target	Test	Control	Target	Test	Control
construisons	construire	battre	astreignons	astreindre	prédire
cuisons	cuire	débattre	atteignons	atteindre	permettre
décrivons	décrire	interrompre	ceignons	ceindre	éprendre
déduisons	déduire	adjoindre	contraignons	contraindre	accroître
détruisons	détruire	recevoir	craignons	craindre	transmettre
élisons	élire	réentendre	dépeignons	dépeindre	ébatte
enduisons	enduire	démètre	déteignons	déteindre	promouvoir
induisons	induire	équivaloir	enfignons	enfreindre	reluire
inscrivons	inscrire	commettre	enjoignons	enjoindre	éconduire
introduisons	introduire	rasseoir	éteignons	éteindre	dissoudre
lisons	lire	conduire	étreignons	étreindre	croître
luisons	luire	omettre	feignons	feindre	extraire
nuisons	nuire	réapprendre	geignons	geindre	raire
prescrivons	prescrire	épandre	joignons	joindre	instruire
produisons	produire	disparaître	oignons	oindre	enclore
récrivons	récrire	échoir	peignons	peindre	coudre
réduisons	réduire	survivre	plaignons	plaindre	convaincre
relisons	relire	maudire	rejoignons	rejoindre	écrire
suffisons	suffire	pourvoir	repeignons	repeindre	méconnaître
traduisons	traduire	séduire	reteignons	reteindre	morfondre
transcrivons	transcrire	ensuivre	teignons	teindre	parfaire

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e) Control [orth/sem]

Target	Orthographic	Semantic	Control
admiron	administrer	apprécier	réfugier
causon	causette	engendrer	signaler
cèdent	centrer	fêter	liquider
célèbrent	celer	abandonner	diriger
conduison	condition	guider	méprendre
correspondon	correction	concorde	vaincre
couvron	couver	abriter	croupir
découvron	demeurer	dévoiler	contenir
disjoignon	disjoncter	séparer	contredire
enlèvent	enlacer	retirer	visiter
instruison	instrument	éduquer	inclure
liquidon	liqueur	débarasser	conseiller
oyon	oublier	débarquer	reservoir
redescendon	redessiner	remarquer	dissocier
repèrent	repenser	imiter	rouler
reproduison	reprocher	provenir	décroître
ressorton	ressouder	émerger	souvenir
saillon	saisir	fasciner	fuir
séduison	serrer	écouter	foutre
veillon	veines	somnoler	briquer
vendon	venter	marchander	surprendre

---



## Summary from Studies 1 and 2

Study 1 showed significant differences between low and high surface frequencies in all verb types tested (i.e., fully regular, morphophonological *e/ε* with orthographical mark, morphophonological *o/ɔ* without orthographical mark, and irregular). Most important, there was a significant effect of cumulative frequency in fully regular and irregular verbs, indicating that forms with high cumulative frequency are recognized faster than form with low cumulative frequency in both high and low surface frequencies. In de irregular verbs, this result suggests that allomorphic stems are separated, but linked represented in the mental lexicon. The morphophonological verbs did not present significant differences between high and low cumulative frequencies, suggesting that they have phonological abstract representations. The *post-hoc* analysis with significant differences between low and high total cumulative frequencies confirmed this hypothesis (Marslen-Wilson & Zhou, 1999).

These results are in line with other studies which investigated morphological representations through the manipulation of lexical and sub-lexical frequencies in priming tasks or simple lexical decisions tasks (Burani et al., 1984; Cole et al., 1989; Michael A. Ford, Marslen-Wilson, & Davis, 2003; Giraudo & Grainger, 2000; Meunier & Segui, 1999a; Taft, 1979). The cumulative frequency suggest that the stem frequency plays a role in word recognition, thus, words might be decomposed for lexical access. Also, we found the cumulative frequency effects in high and low surface frequency, indicating that even in words with high surface frequency, there is an effects of the morphemic frequency. Additionally, there were no differences between the four verb types tested, which do not allow us to differentiate between regular verbs from the 1st class and irregular verbs from the 3rd class; thus, a model with single-mechanism and morphological decomposition for word processing can hold the present results in French inflected verbs.

Study 2 shows full priming in fully regular verbs from the 1st class in [-er] and regular verbs from the 3rd class in [-ir] and partial priming for allomorphic verbs from the 3rd class in [-ire] and in [-indre]. The full priming suggests that the same morpheme was activated in the prime and target, and partial priming suggests that morphologically related morphemes are activated in the prime and target. Therefore, the full priming suggests the full decomposition of primes into stem and inflectional suffixes, and the stem into root and theme vowel in both verbs from the 1st and 3rd classes which have the stem formed by the combination of a root and a theme vowel (e.g., [[[parl]e]r]/[[parl]ons] ‘to speak/we speak’; [[[dorm]i]r]/[[dorm]ons] ‘to sleep/we sleep’).



The partial priming suggests that forms were not fully decomposed and are sub-lexically represented, it means that the stem is not decomposed into root and theme vowel. However, the forms tested which presented the partial priming are actually allomorphic stems from the same verb which cannot be decomposed anymore (e.g., *[[écri]re]/[[écriv]ons]* ‘to write/we write’; *[[joind]re]/[[joign]ons]* ‘to join/we join’). Again, it seems that irregular verbs have allomorphic stems separately, albeit linked, represented in the mental lexicon. Alternatively, it is possible that allomorphic stems are abstractly represented and compute allomorphic rules for the stem formation according to the morphological context. Figure 26 summarizes the main results from Studies 1 and 2.

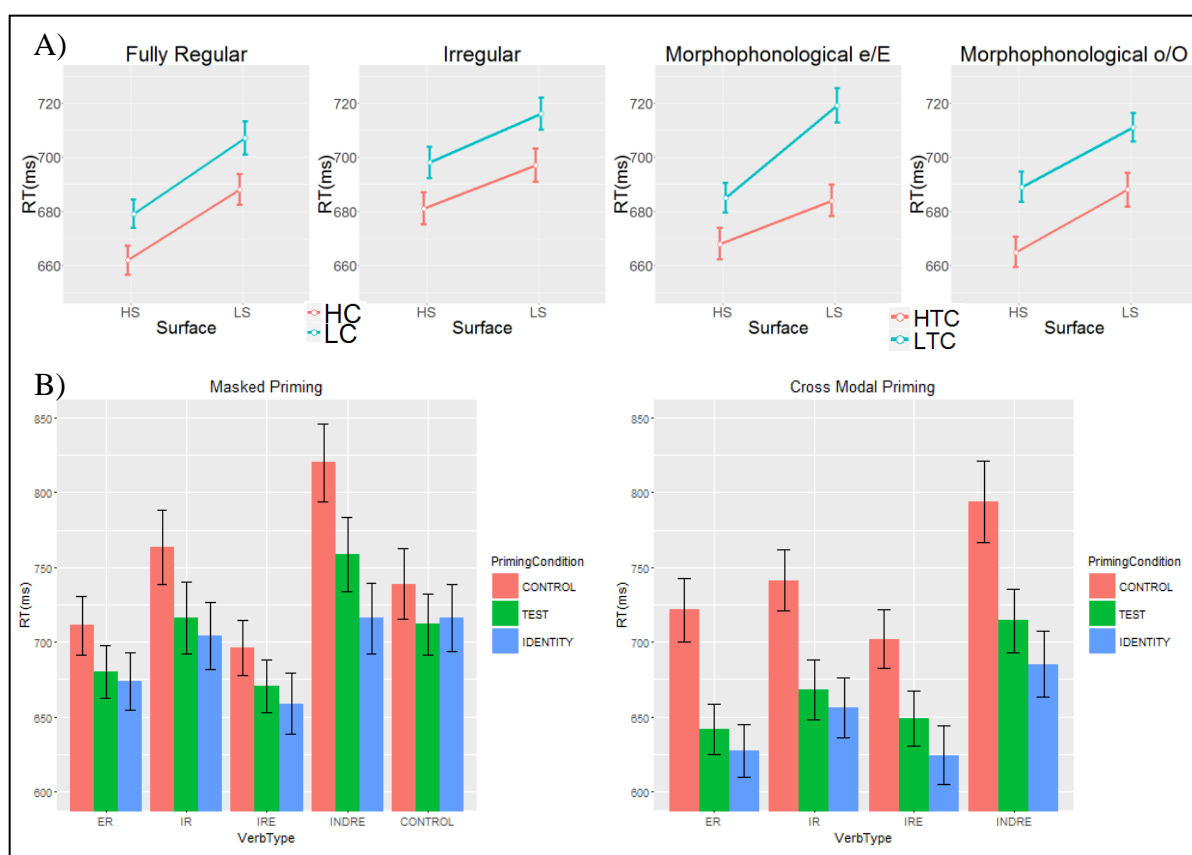


Figure 26 – Summary of results from A) Study 1 and B) Study 2.

Most part of the research in morphological processing is realized by modulating lexical factors as frequency, word length, neighborhood, and semantic transparency in the lexical morpheme, it means, regarding the stem morpheme. After the two studies presented above on the surface and cumulative frequency effects, and the stem formation on French verbs, we became interested in the processing of the verbal inflectional suffixes of tense and agreement in the morphological processing for word recognition in Studies 3, 4, and 5.

### 3.3 Study 3: Morphological Operations in French Verbs



# Morphological Operations in French Verbal Inflection: Automatic, Atomic, and Obligatory

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## Abstract

In this article, we examined how complex words are recognized as being mediated by their morphological operations and structure. French verbal inflection is a paradigmatic system where the stems provide the lexical meaning and the inflectional suffixes activate the functional information by the morphosyntactic features. We investigated the morphological decomposition and inflectional suffixes processing through visual lexical decision tasks. Experiment 1 accessed general differences in the number of morphological operations regarding low and high frequencies, and regular and irregular verbal forms (e.g., *jou-ent/jou-ai-ent* ‘they play/played’, *prend-s/pren-ai-s* ‘you<sub>sg</sub> take/took’). Experiment 2 tested specific differences in the tense and agreement inflectional suffixes (e.g., *jou-ons/jou-i-ons/jou-ez/jou-i-ez* ‘we/you<sub>pl</sub> play/played’). Our hypothesis is that words are automatically decomposed early for morphological processing and that morphemes are later hierarchically recombined for word recognition. We found significant differences between the number of morphological operations in regular and irregular verbs in low and high frequencies; we also found significant differences in tense and agreement suffix processing with longer responses for the past tense and first plural agreement verbal forms, suggesting additive effects in. Our results are in line with single-mechanism pre-lexical decompositional models; we propose a model where stems and inflectional suffixes are processed differently for lexical access and word recognition.

**Keywords:** Morphological Operations; Verbal Inflection; Processing and Representation; Morphemes; Suffixes; Decomposition; Morphological Structure; Word Recognition; Lexical Decision; Psycholinguistics.

# 1 Introduction

Morphological processing has been largely studied in psycholinguistics since the first whole-word (Manelis & Tharp, 1977) and decompositional (Taft, 1979) models. Two main frameworks have survived: search models with symbolic manipulation and rule-based computations (Halle & Marantz, 1994; Stockall & Marantz, 2006) and parallel-distributed-processing (PDP) models based on statistical associations (Baayen et al., 2011; McClelland & Rumelhart, 1981). The former assumes that word recognition is mediated by sub-lexical processing driven by morphological operations, whereas the latter assumes not a morphological level but rather a direct associative system between form and meaning that is based on phonological, orthographic, and semantic overlap. Alternatively, Taft (1994) proposed an interactive-activation model which attributes a strong role to the morphological level, where morphemes are activated through an interactive-association parser.

Research in morphological processing has accumulated results and knowledge mainly with respect to lexical morphemes, such as root and stem representations and processing (Amenta & Crepaldi, 2012; Gustavo Lopez Estivalet & Meunier, 2015a); in contrast, in the present study we propose to more deeply explore the processing of morphological operations and morphosyntactic features, considering the word hierarchical structure (Arregi, 2000; David Embick & Halle, 2005). Inflectional suffixes are morphemes that have regular and paradigmatic behavior in verbal conjugation, such as tense (T) and agreement (Agr) morphemes, activating abstract morphosyntactic features, such as [past/future], and [1st/2nd/3rd person] and [singular/plural], respectively (Halle & Marantz, 1994; Penke et al., 2004). Interestingly, evidence from aphasic patients has shown that tense morphemes are more impaired than agreement ones, underlying the morphological nature of the tense deficit that affects the [past] morphosyntactic feature (Wenzlaff & Clahsen, 2004).

Most part of morphological processing studies has been carried in English, which is an analytic language with poor inflectional morphology. English has only a nominal morpheme for plural [-s]~[-en] (e.g., ball/ball-s, ox/ox-en), and three verbal morphemes for regular past tense [-ed], progressive tense [-ing], and 3rd singular person agreement [-s], (e.g., play/play-

ed/play-ing/play-s). These suffixes are exclusive, never being combined in complex words. In contrast, Romance languages are inflectional languages with rich inflectional morphology; morphemes are combined in complex word formations, such as the French nouns *étudiant* ‘student<sub>male</sub>’, *étudiant-e* ‘student<sub>female</sub>’, *étudiant-s* ‘students<sub>male</sub>’, *étudiant-e-s* ‘students<sub>female</sub>’ and the French verbs *jou-ons* ‘we play’, *jou-i-ons* ‘we played’, *jou-e-r-ons* ‘we will play’, *jou-e-r-i-ons* ‘we would play’. Therefore, it is important to consider the number of morphological operations and the hierarchical morphological structures in word recognition (Marantz, 2013b).

In this study, we investigated the processing of the number of morphological operations and morphosyntactic features activated by different morphemes for word recognition. From our knowledge, this is the first study to address the verbal inflectional morphological operations in Romance languages. We ran two experiments using visual lexical decision tasks. Experiment 1 tested reaction time (RT) differences in function of the number of morphological operations (i.e., one inflectional suffix vs. two inflectional suffixes), verb type (i.e., regular verbs from the 1st class vs. irregular verbs from the 3rd class), and surface frequency (i.e., low surface frequency vs. high surface frequencies) on French verbal forms. Experiment 2 tested the morphological processing of specific tenses (i.e., indicative present vs. indicative imperfect past) and agreements (i.e., 1st plural vs. 2nd plural).

## 1.1 Morphological Processing

From a theoretical perspective, decompositional models with symbolic manipulation are in line with the Item-and-Process architecture, where verbal inflection is the realization of the morphosyntactic features through inflectional suffixes merged to the stem (Halle & Marantz, 1994). In contrast, from an associative Word-and-Paradigm architecture, words are stored as whole-forms in the mental lexicon with their morphosyntactic representations (Anderson, 1992; Jackendoff, 1975). One crucial difference between these two architectures is if words are pre-lexically decomposed for morphological processing or if they are recognized as whole-forms and are post-lexically decomposed to have their morphosyntactic representations activated.

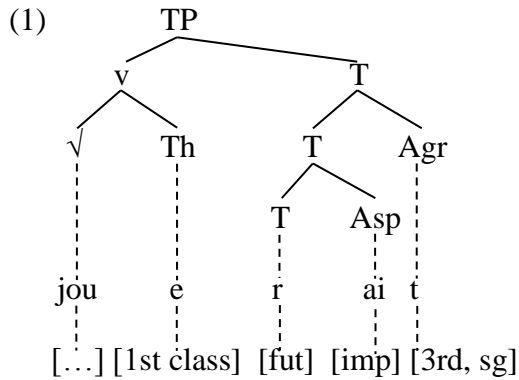
Concerning single-mechanism models, Taft (1979) proposed the Obligatory Decomposition (OD) model with three phases: words are decomposed in morphemes, have their morphemic representations activated in the mental lexicon, and morphemes are

recombined for word verification; this model has recently received strong support from the full decompositional Single Route (SR) model (Stockall & Marantz, 2006). In contrast, Manelis and Tharp (1977) proposed a Whole-Word (WW) model where words are stored in the mental lexicon as full-entries (Jackendoff, 1975). Alternatively, PDP models can be seen as full-entry models in which linguistic representations are the overlap of phonological, orthographic, and semantic information in hidden units (McClelland & Rumelhart, 1981).

Dual-mechanism models solve this dichotomy by proposing two routes for lexical access: a procedural route based on rules and combinatorial processes, and a declarative whole-word route based on associative activation (Ullman, 2001a). Different dual-mechanism models have been proposed, varying in the characteristics that influence the word recognition, such as frequency in the Augmented Addressed Morphology (AAM) model with high-frequency words being recognized by the whole-word route and unknown and low-frequency words by the morphological one (Caramazza, Laudanna, & Romani, 1988), or regularity in the Words and Rules (W&R) model with irregulars being recognized by the whole-word route and regulars by the rule-based one (Pinker, 1999).

## 1.2 French Inflectional Morphology

Unlike Germanic languages, which have reduced inflectional morphology and free stems, Romance languages inherited their rich morphological system from Latin and are analyzed in terms of complex combinations: a) they have no free stems, b) even irregular verbs (mostly from 2nd and/or 3rd classes) with allomorphic stems are merged with inflectional suffixes, and c) all inflected forms contain a minimal computation between lexical and functional morphemes (David Embick & Halle, 2005). Thus, we assume the general French verbal morphological structure in (1) (e.g., *jou-e-r-ai-t* ‘I would speak’  $[[[jou]_{\sqrt{}}[e]_{Th}]_v[[[r]_T[ai]_{Asp}]_T[t]_{Agr}]_T]_{TP}$ , where  $\sqrt{\quad}$  for root, Th for theme vowel, v for stem, T for tense, Asp for aspect, and Agr for agreement), with the morphosyntactic features between squared brackets, adapted from (Arregi, 2000).



In Romance languages such as French, the indicative present and simple past are non-marked tenses, where the root is combined with the theme vowel (i.e., [-e]<sub>1st class</sub>~[-a]<sub>past</sub>, [-i]<sub>2nd class</sub>~[-iss-]<sub>v</sub>, others for 3rd class) for the stem/theme formation, and/or to the agreement morpheme (i.e., .., [-s]<sub>1st/2nd, singular</sub>, [-t]<sub>3rd, singular</sub>, [-ons]<sub>1st, plural</sub>~[-mes]<sub>past</sub>, [-ez]<sub>2nd, plural</sub>~[-tes]<sub>past</sub>, and [-ent]<sub>3rd, plural</sub>), as for example *jou-e/jou-e-s/jou-ons/jou-a-s* ‘I/he play(s)/you<sub>sg</sub> play/we play/you<sub>sg</sub> played’). Indicative imperfect past, simple future, and conditional present are marked tenses. The indicative imperfect past tense has the root directly merged to the tense node that contains the tense morpheme (i.e., [-ai-]<sub>past</sub>~[-i-]<sub>1st/2nd, plural</sub>) and the agreement morpheme (e.g., *jou-ai-s/jou-ai-t/jou-i-ons/jou-i-ez/jou-ai-ent* ‘I/you<sub>sg</sub>/he/we/you<sub>pl</sub>/they played’). Further, the indicative simple future tense has the root combined with the theme vowel, if available, forming the stem/theme; then, the stem is merged with the tense node containing the tense morpheme (i.e., [-r-]~[-rr-]<sub>future</sub>) and the agreement morpheme (i.e., [-ai]<sub>1st, singular</sub>, [-as]<sub>2nd, singular</sub>, [-a]<sub>3rd, singular</sub>, and [-ont]<sub>3rd, plural</sub>). Finally, the conditional present tense has the same inflectional nodes as the indicative simple future, with an additional aspect morpheme (i.e., indicative imperfect past tense morphemes) between the tense and agreement morphemes (Kilani-Schoch & Dressler, 2005).

It follows that the agreement morpheme is present in almost all inflected forms, except for bare stems formed by the root combined with the theme vowel. In sum, words that have only the agreement morpheme have one morphological operation, whereas words that have the tense and agreement morphemes have two morphological operations (Arregi, 2000; Marantz, 2013b).

Although hierarchical morphological structures have been neglected in morphological processing studies, the grammatical computations during word recognition might be very important. Thus, “the morphological features of Tense and Agr have two functions: they check properties of the verb that raises to them, and they check properties of the NP (DP) that



raises to their Spec position; [...] in French overt raising is a prerequisite for convergence; in English is not” (Chomsky, 1993, p.29-30). In French, the stem raises to the tense node and the strong agreement forces overt raising for morphosyntactic feature checking before the spell-out. This allows us to hypothesize that hierarchical morphological structures in Romance languages yield informative results regarding the morphological operations in word recognition (Stockall & Marantz, 2006). It is important to note that while the agreement morpheme is required by syntax to subject-verb concordance, tense is required by the speaker’s intentional situation (Anderson, 1992).

Our past results have shown that all French verbs might be decomposed for lexical access (Gustavo Lopez Estivalet & Meunier, 2015b); Meunier and Marslen-Wilson (2004) found similar cross-modal and masked priming results with regular and allomorphic stem primes for different French verb types (i.e., regular, morphophonological, irregular, and idiosyncratic) and suggested a single-mechanism to process all inflected forms. Manipulating surface and cumulative frequencies, Estivalet and Meunier (2015a) found no differences for morphophonological verbs (e.g., *appeler/appelles* ‘to call/you<sub>sg</sub> weight’, *adorer/adore* ‘to adore/you<sub>sg</sub> adore’), suggesting an underlined phonological representation; most important, they found significant differences between allomorphs in irregular verbs from the 3rd class (e.g., *boire/buvons* ‘to drink/we drink’), suggesting different, albeit linked, stem allomorphic representations or morphological operations in allomorphic stems for word recognition.

In Experiment 1, we explored the hierarchical processing of the inflectional suffixes in the verbal structures with one or two morphological operations. We investigated morphological processing differences as a function of the number of morphological operations in both regular verbs from the 1st class and irregular verbs from the 3rd class and at both low and high surface frequencies. If words are fully decomposed for word recognition, verbs with two inflectional suffixes should present longer RTs than those with only one inflectional suffix. Indeed, a significant effect in the number of morphological operations assumes that each morphological operation has a specific cognitive cost, suggesting pre-lexical decomposition. We predict that there will be a significant difference between regular and irregular verbs, with longer RTs for the latter because of stem allomorphic processing, a significant difference between low and high surface frequencies, and a significant differences in the number of morphological operations in both verb types and both surface frequencies, but no interaction between any of these variables.

The questions that guided Experiment 1 were as follows: a) Are there processing differences between the number of morphological operations (inflectional suffixes) in French verbs? b) Are these differences consistent in regular and irregular French verbal forms? c) Are morphological operations considered differently for low and high surface frequencies?

In Experiment 2, we constrained our investigation to specific tenses and agreements to better understand the hierarchical morphological structure processing of the inflectional suffixes in French verbs. We tracked differences in the processing of morphosyntactic features activated by the indicative imperfect past inflectional suffix. We contrasted two variables with two conditions each: a) tense (i.e., indicative present [ $\emptyset$ ] vs. indicative imperfect past [-i-]) and b) agreement (i.e., 1st plural [-ons] vs. 2nd plural [-ez]) (e.g., *jou-ons/jou-i-ons/jou-ez/jou-i-ez* ‘we/you<sub>pl</sub> play/played’). If words are decomposed into atomic morphemes, verbs in the indicative imperfect past with tense and agreement inflectional suffixes should present longer RTs than verbs in the indicative present containing only the agreement suffix; there should also be no differences between verbs in the 1st and 2nd plural agreements in each verbal tense. However, if words are recognized by their whole-form, there should be no significant difference in the tense and agreement suffixes. Indeed, the [-i-]<sub>past, 1st/2nd, plural</sub> morpheme is a glide semi-vowel phonologically incorporated into the agreement suffix pronunciation and perhaps does not trigger decompositional processes; thus, it is possible that verbs are decomposed only in stem and one suffix (i.e., *jou-ions/jou-iez*), percolating the tense [past] morphosyntactic feature to the agreement morpheme and yielding no significant difference between both tenses.

The questions that drove Experiment 2 were as follows: a) Are there differences in the processing of different tenses in French? b) Are there differences in the processing of different agreements? c) Which is the hierarchical processing of the tense and agreement suffixes? d) Is there an interaction in the processing of tense and agreement suffixes?

Based on the nature of the morphological operations and verbal hierarchical structure, the agreement is an overt operation that is required by syntax for subject-verb concordance, whereas the tense is a covert operation that is required by the speaker’s intentional situation. Thus, we predict that the agreement processing may not have a large cognitive cost, but that the processing of tense might impact the hierarchical morphological structure processing and, consequently, slow the RTs in word recognition. Finally, an interaction between tense and agreement would suggest a dependent processing of these suffixes.

## 2 Method

### 2.1 Experiment 1: Verbal Morphological Operations

#### 2.1.1 Participants

A total of 30 adult native speakers of French between the ages of 18 and 31 (mean age 21.41, 15 women) took part in Experiment 1. All participants were right-handed, had normal hearing, had normal vision or corrected by glasses or contact lenses, and had no history of cognitive or language disorders. All participants were students at the *Université Lumières Lyon 2*. Participants did not know the purpose of the study and gave their written consent to participate in the experiment as volunteers. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the ethics committee *Comité de Protection des Personnes Sud-Est II* (IRB: 00009118).

#### 2.1.2 Material and design

Participants performed a lexical decision task in visual modality between words and pseudowords. We investigated two verb types: a) regular verbs from the 1st class (e.g., *aimait* ‘he loved’) and b) irregular verbs from the 3rd class (e.g., *buvait* ‘he drunk’). In both verb types, we investigated the number of morphological operations: a) verbs with one inflectional suffix (S-) (e.g., *aim-ons* ‘we love’, *buv-ons* ‘we drink’) and b) verbs with two inflectional suffixes (S+) (e.g., *aim-ai-t* ‘he loved’, *buv-ai-t* ‘he drunk’). Furthermore, we investigated these effects in a) low surface frequency (SF-) and b) high surface frequency (SF+), as shown in Table 1.

We selected 160 verbal forms as experimental items: 80 regular forms from the 1st class and 80 irregular forms from the 3rd class. Within each verb type, 40 forms were of low surface frequency, and 40 forms were of high surface frequency. Then, in each verb type and surface frequency subgroup, there were 20 forms with one morphological operation and 20 forms with two morphological operations (Appendix A). All experimental items were matched in lemma frequency, surface frequency, number of letters, number phonemes, number of syllables, and neighborhood calculated by the Orthographic and Phonological Levenshtein Distance between the 20 closest words (OLD20 and PLD20) (Yarkoni et al., 2008), as shown in Appendix B.

Verb Type	Frequency	One suffix (S-)	Two suffixes (S+)
Regular	SF-	travers-ons	travers-ai-s
	SF+	parl-ez	parl-i-ez
Irregular	SF-	joign-ent	joign-ai-t
	SF+	buv-ons	boi-r-ai

Table 1 – Examples of stimuli in the different conditions of Experiment 1: verb type, surface frequency, and morphological operations. S- for one inflectional suffix, S+ for two inflectional suffixes, SF- for low surface frequency, and SF+ for high surface frequency.

Using a different set of 160 French verbal forms, we created French pseudowords changing one or two letters. All experimental items were selected and controlled using the French database *Lexique* (New et al., 2004), and the pseudowords were created using its pseudoword generator toolbox. Four different lists were constructed using the Mix program (van Casteren & Davis, 2006) with pseudorandom orders to counterbalance the sequence of stimuli presentation between conditions. The lists had the following criteria: a) a stimulus was never preceded by another stimulus starting with the same letter, b) there were at most three words or pseudowords in sequence, and c) there were at least 10 stimuli between experimental stimuli from the same condition. In total, Experiment 1 included 320 stimuli and 10 practice stimuli; it lasted approximately 18 minutes.

### 2.1.3 Procedure

Experiment 1 was constructed and ran using E-Prime® 2.0 Professional (Psychology Software Tools, Inc., Sharpsburg, PA, USA) (Schneider et al., 2012). Participants were tested individually in a quiet room in the library of the *Université Lumières Lyon 2*. Each trial followed the sequence: first, a fixation point was displayed on the center of the screen for 500 ms; the target word was then presented on the center of the screen in lowercases for 2,000 ms or until the participant's response; then, a blank screen was presented as inter-stimuli for 500 ms, and a new trial started with the fixation point. The stimuli were presented on the center of a 15" LCD computer screen, in letter size 18-point Courier New font, in white letters against black background. RT measure began in the onset of the target screen and finished when the participants performed their responses via a keyboard button.

Participants were asked to perform a lexical decision task as quickly and accurately as possible using a computer keyboard with both hands, where the right hand on the ‘green’ button corresponded to words and the left hand on the ‘red’ button corresponded to pseudowords.

### 2.1.4 Results

Only experimental items were analyzed. RTs faster than 300 ms and slower than 1,600 ms were considered out of task and discarded (.71%); one experimental stimulus (i.e., *vaille* ‘I/it worth’) was removed because it had an error rate higher than 50% (.61%); and incorrect responses were removed for the RT analysis (6.92%). In total, 8.15% of the data were discarded. Overall RT means, standard deviations (SD), and error rates are shown in Table 2.

Verb Type	Frequency	One suffix (S-)		Two suffixes (S+)	
		RT(ms)	Error(%)	RT(ms)	Error(%)
Regular	SF-	669(171)	.95	692(178)	1.03
	SF+	644(159)	.34	664(182)	.72
Irregular	SF-	704(187)	.93	721(221)	1.44
	SF+	669(167)	.42	696(202)	1.10

Table 2 – Overall RT means, SDs between parenthesis, and error rates by the different conditions of Experiment 1. S- for one suffix, S+ for two suffixes, SF- for low surface frequency, and SF+ for high surface frequency.

Reversed RTs presented a more like-Gaussian distribution when compared to normal RTs and logarithmic function of RTs through the Kolmogorov-Smirnov test (i.e., RT:  $D = .128$ ,  $p < 2.2e-16$ ; log(RT):  $D = .075$ ,  $p < 2.2e-16$ ; 1/RT:  $D = .028$ ,  $p < .002$ ), thus making them more suitable for the application of parametric tests. The data were analyzed using two mixed-effect models (Baayen, Davidson, & Bates, 2008), one with the inverted RTs as the dependent variable, participants and targets as random variables, and verb type (i.e., regular vs. irregular), number of morphological operations (S- vs. S+, where S- for one inflectional suffix and S+ for two inflectional suffixes), and surface frequency (SF- vs. SF+, where SF-

for low surface frequency and SF+ for high surface frequency) as fixed-effect variables; and another model with the logit accuracy (ACC) as the dependent variable and binomial family specified in the model.

The main RT effects through an analysis of variance (ANOVA) in the mixed-effect model (Type III with Satterthwaite approximation for degrees of freedom) revealed a significant effect of verb type ( $F(1,151) = 11.412, p < .001$ ), with longer RTs for irregular than regular verbs; a significant effect of surface frequency ( $F(1,151) = 17.059, p < .001$ ), with longer RTs for low- than high-frequency words; and a significant effect of the number of morphological operations ( $F(1,151) = 6.241, p < .01$ ), with longer RTs for verbs with two morphological operations than verbs with one morphological operation. None of the interactions were significant ( $F_s < 1, p_s > .1$ ).

In the error rate analysis, the ANOVA in the mixed-effect model (Type II Wald  $\chi^2$  test) showed a significant effect of verb type ( $\chi^2(1, N = 30) = 4.041, p < .05$ ), with more errors in irregular than regular verbs; a significant effect of surface frequency ( $\chi^2(1, N = 30) = 7.423, p < .01$ ), with more errors for low- than high-frequency words; and a significant effect in the number of morphological operations ( $\chi^2(1, N = 30) = 4.017, p < .05$ ), with more errors in verbs with two morphological operations than one morphological operation. None of the interactions were significant ( $p_s > .1$ ).

### 2.1.5 Discussion

The results presented above show three significant main effects and no interaction between them: a main effect of verb type, a main effect of surface frequency, and a main effect of the number of morphological operations.

Of principal interest in this article, verbs with two morphological operations yield longer RTs than verbs with one morphological operation in the processing of inflectional suffixes on French verbs. These results were consistent in both regular and irregular verbs and for both low and high surface frequencies, with no interactions between these variables. We therefore consider that the processing of each inflectional suffix has an additive cognitive cost reflected in the RTs and that the lack of interaction between morphological operations and surface frequency indicates no processing difference for low and high surface frequency words. Additionally, the error rate results confirmed the same pattern of results with higher errors for forms with two morphological operations.

We also found an effect of verb type, with irregular verbs associated with longer RTs and more errors than regular ones. The lack of interactions with the other variables suggests that they are independent effects and that regular and irregular verbs are equally processed regarding the inflectional suffixes (Ruth de Diego Balaguer et al., 2006; Orsolini & Marslen-Wilson, 1997). Our interpretation is that stem competition or allomorphic operations on irregular verbs slow their RTs (Gustavo Lopez Estivalet & Meunier, 2015b).

The surface frequency effect observed is widely known in the psycholinguistic literature, but its interpretation varies (Amenta & Crepaldi, 2012); nevertheless, this variable did not interact with any other variable in our data, holding the effect of the number of morphological operations for both low and high surface frequency verbs. Thus, our interpretation is that the surface frequency reflects consistent and productive combinations of morphemes in word formation (Stockall & Marantz, 2006; Taft, 1979).

We remark that the phonological/orthographic differences between inflected verbs with one or two morphological operations occur mainly in the tense morpheme, given that the agreement morpheme is present in almost all inflected forms. Therefore, the presence of the tense morpheme adds phonological/orthographic material to be processed. Considering that the tense node is processed by covered movement, activating intentional situational features and that the agreement node is processed by overt movement for subject-verb concordance, we propose that these two morphological nodes are hierarchically processed by different cognitive processes. Thus, these results prompted new questions about the nature of specific verbal inflectional suffixes: a) Is there a difference between the processing of the indicative present tense and indicative imperfect past tense (i.e., indicative present [ $\emptyset$ ]<sub>present</sub> vs. indicative imperfect past [-i-]<sub>past</sub>)? b) Is there a difference between the processing of agreement morphemes with different morphosyntactic features (i.e., *nous* ‘we’  $\leftrightarrow$  [-ons]<sub>1st, plural</sub> vs. *vous* ‘you’  $\leftrightarrow$  [-ez]<sub>2nd, plural</sub>)? To answer these questions, Experiment 2 focused on the processing of specific inflectional suffixes on French verbs.

## 2.2 Experiment 2: Tense and Agreement Suffix Processing

### 2.2.1 Participants

Twenty-two adult native speakers of French between the ages of 18 and 33 (mean age 23.18, 11 women) with the same characteristics as Experiment 1 took part in Experiment 2; no participant performed both experiments. Participants did not know the purpose of the study and gave their written consent to participate in the experiment as volunteers. The study was conducted in accordance with the Declaration of Helsinki, and the protocol was approved by the ethics committee *Comité de Protection des Personnes Sud-Est II* (IRB: 00009118).

### 2.2.2 Material and design

Participants performed a lexical decision task in visual modality on words and pseudowords. We investigated tense and agreement suffix processing in regular verbs from the 1st class. We handled four different experimental conditions as a function of two variables with two conditions each: a) tense (i.e., indicative present [ $\emptyset$ ] vs. indicative imperfect past [-i-]) and b) agreement (1st plural [-ons] vs. 2nd plural [-ez]), as shown in Table 3.

Tense	Present		Imperfect Past	
	1st plural	2nd plural	1st plural	2nd plural
Structure	[[jou] <sub>v</sub> [ons] <sub>Ag</sub> ] <sub>TP</sub>	[[jou] <sub>v</sub> [ez] <sub>Ag</sub> ] <sub>TP</sub>	[[jou] <sub>v</sub> [[i] <sub>T</sub> [ons] <sub>Ag</sub> ] <sub>TP</sub>	[[jou] <sub>v</sub> [[i] <sub>T</sub> [ez] <sub>Ag</sub> ] <sub>TP</sub>
Orthography	jouons	jouez	jouions	jouiez
Phonology	/ʒu'ɔ̃/	/ʒu'e/	/ʒu'jɔ̃/	/ʒu'je/
Gloss	'we play'	'you <sub>pl</sub> play'	'we played'	'you <sub>pl</sub> played'

Table 3 – Examples of stimuli in the different conditions of Experiment 2: tense (indicative present vs. indicative imperfect past) and agreement (1st plural vs. 2nd plural).

We selected 320 French regular verbs from the 1st class falling in the four different experimental conditions: 160 verbs in the indicative present tense and 160 verbs in the indicative imperfect past tense. Within each tense, 80 verbs were inflected in the 1st plural agreement, and 80 verbs were inflected in the 2nd plural agreement (Appendix C). We



selected this large set of experimental stimuli for further multivariate analyses. All experimental stimuli and conditions were controlled and matched in lemma frequency between 5 and 300, surface frequency between .07 and 5, number of letters between 5 and 10, number of phonemes between 3 and 10, number of syllables between 2 and 4, 0 homographs, OLD20 and PLD20 (Yarkoni et al., 2008), as shown in Appendix D.

We also added a set of 40 infinitive verbs as fillers; then, we added a set of 360 pseudowords to counterbalance the responses. All experimental items were selected, controlled, and matched using the French database *Lexique* (New et al., 2004); the pseudowords were also created by using its pseudoword generator toolbox. Four lists were constructed with the same criteria as Experiment 1 using the Mix program (van Casteren & Davis, 2006) with pseudorandom order to counterbalance the sequence of stimuli presentation between conditions. In total, Experiment 2 had 720 stimuli and 12 practice stimuli; it was held in approximately 32 minutes, with two pauses during the experiment.

### 2.2.3 Procedure

The procedure for Experiment 2 was the same as for Experiment 1.

### 2.2.4 Results

Only experimental items were analyzed. RTs faster than 300 ms and slower than 1,600 ms were considered out of task and discarded (1.04%), and incorrect responses were removed for the RT analysis (3.47%). In total, 4.47% of the data were discarded. The overall RT means, SDs, and error rates are shown in Table 4.

Tense	Present		Imperfect Past		Total	
	RT(ms)	Error(%)	RT(ms)	Error(%)	RT(ms)	Error(%)
1st plural	653(194)	.66	693(211)	1.62	677(204)	2.28
2nd plural	636(183)	.63	660(184)	.56	643(183)	1.19
Total	645(189)	1.29	676(199)	2.18	660(195)	3.47

Table 4 – Overall RT means, SDs between parenthesis, and error rates by the different conditions of Experiment 2.

As in Experiment 1, reversed RTs presented the more like-Gaussian distribution (Kolmogorov-Smirnov test, RT:  $D = .126, p < 2.2e-16$ ; log(RT):  $D = .073, p < 2.2e-16$ ; and 1/RT:  $D = .022, p < .006$ ). The data were analyzed using two-mixed effect models (Baayen et al., 2008), one with inverted RTs as the dependent variable, participants and targets as random variables, and tense (indicative present vs. indicative imperfect past) and agreement (1st plural vs. 2nd plural) as fixed-effect variables; and another model with logit ACC as the dependent variable and binomial family specified in the model.

The ANOVA in the RT mixed-effect model showed a significant effect of tense ( $F(1,306) = 29.291, p < .001$ ), with longer RTs for verbs in the indicative imperfect past tense than present one; a significant effect of agreement ( $F(1,306) = 28.456, p < .001$ ), with longer RTs for the 1st plural agreement than 2nd plural one; and a significant interaction between these two variables ( $F(1,306) = 7.583, p < .01$ ), indicating that both effects are dependent on each other. The planned comparisons showed that the tense effect is bigger for the 1st plural ( $t(309) = 5.762, p < .001$ ) than for the 2nd plural ( $t(304) = 2.884, p < .05$ ) agreement suffix.

The ANOVA in the error rate analysis showed a significant effect in tense ( $\chi^2(1, N = 22) = 5.630, p < .05$ ), with more errors for verbs in the indicative imperfect past tense than present one; a significant effect in agreement ( $\chi^2(1, N = 22) = 12.197, p < .001$ ), with more errors for 1st plural agreement than 2nd plural one; and a significant interaction between these two variables ( $\chi^2(1, N = 22) = 6.536, p < .05$ ). The planned comparisons showed a significant difference between present and imperfect past tenses in the 1st plural agreement ( $z = -3.117, p < .001$ ), but not in the 2nd plural agreement ( $z = .676, p = .499$ ).

To better comprehend our data, we scrutinized more complex mixed-effect models with multivariate analyses, including numerical surface frequency, lemma frequency, number of letters, number of phonemes, number of syllables, and OLD20 and PLD20 as fixed-effect variables. We started analyzing more complex models with many general additive effects and interactive effects between tense and agreement against other variables; we then proceeded to simplify the model by eliminating non-significant variables and interactions. We analyzed nine different models and compared them by using an ANOVA between the models (Baayen et al., 2008); the ANOVA of the most significant mixed-effect multivariate model (i.e., lmerH:  $\chi^2(9, N = 22) = 99.625, p < .001$ ) is shown in Table 5. The other mixed-effect multivariate models that were analyzed, as well as the ANOVA of the most complex model analyzed, are shown in Appendix E.

Variables	MSE	NumDF	DenDF	F.value	Pr(>F)	
Tense	2.7049	1	306.34	33.156	2.067e-08	***
Agreement	1.5420	1	306.40	18.902	1.875e-05	***
LemmaFreq	8.5876	1	312.98	105.264	< 2.2e-16	***
Letters	0.8028	1	304.87	9.841	0.001874	**
Syllables	0.6609	1	307.00	8.101	0.004723	**
Tense:Agreement	0.5163	1	306.28	6.328	0.012394	*

\*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$

Table 5 – ANOVA results from the multivariate mixed-effect model, including factorial tense and agreement; and numerical lemma frequency, number of letters, and number of syllables as fixed-effect variables (i.e.,  $\text{lmerH} <- \text{lmer}(-1000 * 1/\text{RT} \sim \text{Tense} * \text{Agreement} + \text{LemmaFreq} + \text{Letters} + \text{Syllables} + (1|\text{Participant}) + (1|\text{Target}), \text{data})$ ).

### 2.2.5 Discussion

Experiment 2 confirmed our prediction of a significant effect in the morphological processing of the tense suffix, yielding a consistent difference between indicative present and imperfect past in French verbs; unexpectedly, we also found a significant effect of agreement with longer RTs for the 1st plural agreement than the 2nd plural one. There was also a significant interaction between tense and agreement, showing a stronger effect of tense in the 1st plural agreement than in the 2nd plural one. It seems that the processing of the tense morpheme as an infix between the stem and the agreement morpheme has consequences on word recognition RTs and error rates. Our results speak to differences in the processing of the tense and agreement morphemes.

The tense effect observed show that verbs inflected in the indicative imperfect past with two morphological operations yield longer RTs than verbs inflected in the indicative present with one morphological operation. Still, it appears that this effect is modulated by the agreement morpheme. In the indicative imperfect past tense, when the tense and agreement morphemes are merged, their respective morphosyntactic features percolate to the tense intermediary node (i.e.,  $\langle -ions \rangle \leftrightarrow /'j\ddot{o}/ \leftrightarrow [\text{past}, 1\text{st}, \text{plural}]$ ;  $\langle -iez \rangle \leftrightarrow /'je/ \leftrightarrow [\text{past}, 2\text{nd}, \text{plural}]$ ). Therefore, in contrast to the underspecified standard indicative present tense, which has neither the tense morpheme nor tense morphosyntactic features to be processed, the

indicative imperfect past tense has additionally the [past] morphosyntactic feature to be processed, slowing the RTs (Penke et al., 2004).

In contrast to what was expected, we found a significant difference between the 1st and 2nd plural agreements; we suggest that this difference could be because the 2nd plural agreement (i.e., *vous* ‘you<sub>pl</sub>’ ↔ [-ez]<sub>2nd, plural</sub>) is the standard formal pronoun of treatment in French, very frequent, very productive, and highly disseminated in written and oral language, whereas the 1st plural agreement (i.e., *nous* ‘we’ ↔ [-ons]<sub>1st, plural</sub>) has been largely substituted by the standard impersonal 3rd singular form (i.e., *on* ‘we/one’) (Kilani-Schoch & Dressler, 2005). Consequently, it is possible that the 2nd plural agreement [-ez] simply has the [2nd] morphosyntactic feature underspecified because it is the standard [plural] agreement morpheme; thus, it would have one morphosyntactic feature less to be processed (i.e., [-ez]<sub>plural</sub>), accelerating RTs (Halle & Marantz, 1994; Penke et al., 2004). Indeed, the 2nd plural agreement morpheme [-ez] (i.e., token: 5828, type: 9240.9) is much more frequent than the 1st plural [-ons] (i.e., token: 2757, type: 2799.9), measured as bigram/trigram frequencies (New et al., 2004), and moreover the word length control and matching, it is a fact that the 1st plural agreement suffix [-ons] is one letter larger than the 2nd plural one [-ez].

It also appears that tense effect between indicative present and imperfect past in RTs and error rates is larger in the 1st plural agreement than in the 2nd plural. Nevertheless, the mixed-effect multivariate model scrutinized in Appendix E suggests that the interaction between tense and agreement is not robust. In this model, tense and agreement do not interact with any other variable, and the interaction between tense and agreement disappears when the other lexical variables are included in the analyses (Baayen et al., 2008). As expected, in the models analyzed there were neither surface frequency, nor phonological length, nor neighborhood (i.e., OLD20 and PLD20) effects; in contrast, in Table 5 and Appendix E, analyses yielded letter and syllable length significant results, which is largely known as reflecting sensory stimuli length perception and processing (Caramazza, 1997; McClelland & Rumelhart, 1981; Taft, 1991). Most importantly, as predicted by the OB model there was an expected significant effect of lemma frequency, which supports early obligatory decomposition of verbs between stem and inflectional suffixes and morphemic search for word recognition (Amenta & Crepaldi, 2012; Gustavo Lopez Estivalet & Meunier, 2015a; Stockall & Marantz, 2006; Taft, 1979). Therefore, in line with large orthographic decomposition evidence (Rastle & Davis, 2008), our results suggest that lemma frequency and morphological operations are additive effects in the visual recognition of inflected words. Whereas the lemma frequency effect reflects the search of morphemic representations for

activation in the mental lexicon, the morphological operation effect would reflect the morphosyntactic features checking in the combination of morphemes for word verification and recognition.

## 3 General Discussion

In the present study, we investigated the processing of inflectional suffixes in French verbs, obtaining significant effects in the processing of a different number of morphological operations in tense and agreement morphemes. Our results suggest that words are not the atoms of languages, but that words are processed in terms of hierarchical morphological structures, activating morphemes as minimal meaningful units in word recognition (Halle & Marantz, 1994). These results are in line with studies that present evidence of pre-lexical decomposition for word recognition (Ruth de Diego Balaguer et al., 2006; Rastle & Davis, 2008; Stockall & Marantz, 2006; Taft, 1979), as are our recently findings and other studies in French verbal morphology (Gustavo Lopez Estivalet & Meunier, 2015a, 2015b; Meunier & Marslen-Wilson, 2004; Royle, Drury, Bourguignon, & Steinhauer, 2012). The main novelty in our results is that we investigated the morphological processing of inflectional suffixes in French verbs independently of the root and stem processing, addressing the abstract morphosyntactic features activated by the tense and agreement suffixes in the hierarchical morphological structure (Arregi, 2000; Halle & Marantz, 1994).

### 3.1 Hierarchical Morphological Structure

We found significant differences between French verbal forms with one or two morphological operations in high surface frequency and irregular verbs, as the irregular verbs were also significantly slower than regular ones. These findings seem to rule out whole-word representation models (Baayen et al., 2011; Devlin et al., 2004; Manelis & Tharp, 1977; McClelland & Rumelhart, 1981) and dual-mechanism models that posit a whole-word route for high-frequency words, such as the AAM (Caramazza et al., 1988), or irregular words, such as the W&R (Pinker, 1999) and the declarative/procedural model (Ullman, 2001a), but not the Parallel Dual-Route model (Baayen et al., 1997), where the decompositional route would always win the race for word recognition in French. Alternatively, the Minimalist Morphology model (Wunderlich, 1996) predicts a semi-structured mechanism for irregular

words, with post-lexical decomposition and allomorphic representations in a Word-and-Paradigm architecture. However, our results speak in favor of pre-lexical decomposition and rule-based morphological processing, which is more in line with an Item-and-Process architecture (Halle & Marantz, 1994). Therefore, it seems that single-mechanism models can better fit our results, especially regarding single visual word recognition and morphological processing triggered by orthographic activation in early stages (Amenta & Crepaldi, 2012; Rastle & Davis, 2008; Taft, 1991).

If envisaging dual-mechanism models, it appears that they should be considered not in terms of exclusive different routes but in terms of different levels of word processing (Allen & Badecker, 2002; Caramazza, 1997; Crepaldi et al., 2010; Jackendoff, 1975). De Diego Balaguer et al. (2006) showed functional magnetic resonance (fMRI) results indicating that both regular and irregular Spanish inflected verbs activate areas related to grammatical processing (the left inferior frontal gyrus). While irregulars also activate areas of the prefrontal cortex, reflecting lexical retrieval, regular verbs show an increased activation of areas related to the phonological loop in the reutilization of the stem shared across regular forms (anterior superior temporal gyrus and hippocampus).

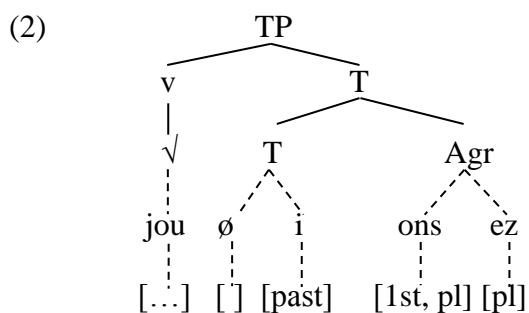
It should be noted that Romance languages almost always present these different levels of word processing as they almost always have inflectional suffixes independently of stem regularity (e.g., French: *je joue/je jouai, je prends/je pris*; Italian: *io giocaio giocavo, io prendo/io presi*; Spanish: *yo juego/yo jugué, yo cojo/yo cogí*; Gloss: ‘I play/I played, I take/I took’); therefore, word recognition in Romance languages is always mediated by the access of the lexical morpheme with semantic features and the functional morpheme with morphosyntactic features. In contrast, Germanic languages, for example, present regular forms with few suffixes and irregular allomorphic forms as free stems (e.g., English: ‘I play/I played, I take/I took’; German: *Ich spiele/Ich spielte, Ich nehme/Ich nahm*; Dutch: *Ik speel/Ik speelde, Ik neem/Ik nam*); hence, word recognition of irregular verbs is the only access of the allomorphic lexical morpheme providing semantic features (and probably a [past] feature) (Wunderlich, 1996).

Our results showing differences in the processing of tense and agreement inflectional suffixes are also in line with those of aphasic patients, which show that tense is more impaired than agreement morpheme processing. Thus, our results support the interpretable feature hypothesis, where competence in morphological hierarchical structure processing and word recognition is directly dependent on morphosyntactic interpretable features (Wenzlaff &

Clahsen, 2004). Therefore, the decompositional combinatorial route is the general mechanism for morphological processing; in particular, languages with rich inflectional morphology largely explore this mechanism (Orsolini & Marslen-Wilson, 1997).

### 3.2 Frameworking Inflectional Processing

We suggest that the processing differences and interaction between tense and agreement nodes take place during the activation and recombination phases based in the hierarchical morphological structure processing. In the activation phase, lexical morphemes activate semantic features and functional morphemes activate morphosyntactic features (Ruth de Diego Balaguer et al., 2006; Halle & Marantz, 1994). It follows that in the morphological marked tenses, such as the indicative imperfect past, there is not only more phonological/orthographic material to be processed but also important morphosyntactic features activated by the tense suffix to be processed for word recognition. According to schema (1) and the Experiment 2 critical stimuli shown in Table 3, French verbs inflected in the indicative present and imperfect past tenses in the 1st and 2nd plural agreements have neither the theme vowel nor the aspect morpheme, which is represented as (2):



In sum, the tense node is decomposed for morphosyntactic feature processing; the agreement morpheme is an overt operation required by syntax, which is quickly and easily feature checked in the subject-verb concordance, and the tense morpheme is a covered operation that conveys the speaker's intentional situation in the word formation (Avram Noam Chomsky, 1993). It seems that agreement processing is easy and does not require large cognitive resources; in contrast, the tense processing is deeper and demands greater cognitive resources, slowing the RTs. We speculated that the small differences between the 1st and 2nd plural agreements could be explained by the underspecified morphosyntactic features

processing. If the 2nd person is the standard [plural] agreement morpheme, it is underspecified in the person morphosyntactic feature (i.e., [-ez]<sub>plural</sub>); thus, there is one morphosyntactic feature less than the 2nd plural agreement (i.e., [-ons]<sub>2nd, plural</sub>) to be processed, accelerating the RTs (Penke et al., 2004).

We suggest that the different verbal inflectional nodes are processed hierarchically, separately, and interactively for word recognition. Our proposition is in line with morphological verbal inflectional studies presenting EEG evidence in French (Royle et al., 2012) and Catalan (Rodríguez-Fornells et al., 2001), magnetoencephalographic evidence in English (Stockall & Marantz, 2006), fMRI evidence in Spanish (Ruth de Diego Balaguer et al., 2006), aphasic evidence in German (Wenzlaff & Clahsen, 2004), and theoretical linguistics evidence in Spanish (Arregi, 2000) and Latin (David Embick & Halle, 2005).

We would like to remark that while theoretical linguistics clearly separates the conceptual-intentional internal language machinery and the sensorial motor interface for language externalization (Anderson, 1992; Avram Noam Chomsky, 1993; Halle & Marantz, 1994; Jackendoff, 1975), psycholinguistic models sometimes intricate the sensorial interface with the language conceptual system (Baayen et al., 2011; Crepaldi et al., 2010; Devlin et al., 2004; McClelland & Rumelhart, 1981; Rastle & Davis, 2008; Taft, 1994), with the latter yielding results that can be generally fitted by PDP modeling, but which hardly correspond to the psycholinguistic computational reality. In what follows, we delineate the main framework of our single-mechanism model for morphology processing with pre-lexical and automatic decomposition, and symbolic-manipulation in an Item-and-Process architecture.

We propose that first, orthographic features information is processed by the visual sensory system based on n-gram frequency and constituency in an interactive-activation parser (Taft, 1991, 1994), thereby delivering enough evidence for triggering word decomposition (Rastle & Davis, 2008). Second, specific n-grams are encoded as morphemes; then, morphemic representations are searched and activated in the lexeme level, and subsequently their abstract representations are activated in the lemma level in the mental lexicon (Allen & Badecker, 2002), yielding the lemma frequency effect. Whereas lexical morphemes are numerous, present complex semantic features for meaning activation and phonological form in stem processing, functional morphemes are limited, present specific relevant morphosyntactic features and phonological form (Marantz, 2013b). Thus, suffixes are the best candidates to be represented and quickly processed in this phase; they are small units from one to three letters that are regular and systematic, presenting high



phonological/orthographic consistency and grammatical function. Third, morphemes are hierarchically recombined in the word structure for the word verification and recognition (Stockall & Marantz, 2006; Taft, 1979). Baayen et al. (1997) describes these phases in segmentation, licensing, and composition, respectively; however, the licensing phase in our model would be within the recombination phase, when forms are verified and licensed as real and meaningful words.

## 4 Conclusions

In the present study, we presented evidence from two visual lexical decision experiments on French verbal inflectional suffixes that words are decomposed for lexical access and recognition. We showed that the number of morphological operations in inflected words is crucial in morphological decomposition and processing. Tense and agreement inflectional suffixes presented different behaviors. Tense marking is largely exploited in Romance languages and appears to influence the processing of other morphemes in the morphological structure in word recognition (Ruth de Diego Balaguer et al., 2006). These results can be interpreted by a single-mechanism model with automatic pre-lexical decomposition where regular and irregular, low and high surface frequency, simple and complex words are processed by the same mechanism in different levels of word processing.

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# Appendix A

## Experiment 1

Regular				
Lemma	SF+/S+	SF+/S-	SF-/S+	SF-/S-
adresser	adressais	adressent	adressera	adressons
ajouter	ajoutais	ajoutent	ajoutera	ajoutes
changer	changera	changent	changions	changeons
coucher	couchais	couchent	couchiez	couchons
décider	décidera	décident	décidiez	décidez
dépêcher	dépêchait	dépêchons	dépêchais	dépêchent
dîner	dînait	dînons	dîniez	dînent
estimer	estimais	estiment	estimiez	estimons
expliquer	expliquera	expliquent	expliquiez	expliquons
fatiguer	fatiguait	fatiguent	fatiguera	fatiguons
montrer	montrais	montrez	montriez	montrons
poser	posais	posent	posiez	posons
presser	pressais	pressons	pressera	pressent
raconter	racontais	racontez	racontiez	racontons
risquer	risquais	risquent	risquiez	risquons
sauver	sauvera	sauvent	sauvais	sauvons
supposer	supposais	supposons	supposiez	supposent
tourner	tournais	tournons	tournera	tournez
traverser	traversais	traversons	traversera	traversez
tromper	trompais	trompent	trompiez	trompons

Irregular				
Lemma	SF+/S+	SF+/S-	SF-/S+	SF-/S-
apercevoir	apercevait	aperçoit	apercevrai	aperçoives
apprendre	apprendra	apprends	apprendrez	apprenons
boire	boirai	buvions	boiras	buvez
connaître	connaissiez	connaît	connaîtrez	connaisses
craindre	craignait	crains	craindra	craignes
devenir	devenais	deviens	deveniez	devient
envoyer	envoyaient	envoie	envoyions	envoies
mourir	mourait	meurent	mouriez	meures
obtenir	obtenait	obtient	obtiendra	obtenons
parvenir	parvenais	parviens	parveniez	parvient
prévenir	prévenait	prévient	prévenais	préviens
recevoir	recevaient	reçoivent	recevions	reçoives
rejoindre	rejoignaient	rejoins	rejoignais	rejointes
reprendre	reprenaient	reprends	reprentras	reprenons
retenir	retenait	retient	retenions	retiens
revoir	revoyais	revoit	reverront	revoyons
souvenir	souvenaient	souviene	souvenions	souviennes
surprendre	surprenait	surprend	surprendra	surprenons
tenir	tenions	tient	teniez	tiens
valoir	valaient	vaille	valais	vailent

---

## Appendix B

VT	Suffix	Lemma	Surface	Letter	Phoneme	Syllable	OLD20	PLD20
Regular								
SF-	S-	194.86	0.52	8.05	5.60	2.20	1.95	1.40
SF-	S+	194.86	0.41	8.25	6.65	2.85	2.10	1.40
SF+	S-	194.86	3.78	8.10	4.80	2.15	1.94	1.45
SF+	S+	194.86	3.75	8.20	5.80	2.70	1.93	1.17
Irregular								
SF-	S-	198.84	0.43	8.75	6.10	2.40	2.04	1.71
SF-	S+	198.84	0.49	8.60	6.60	2.80	2.19	1.67
SF+	S-	198.84	3.77	8.35	5.45	2.15	1.99	1.65
SF+	S+	198.84	4.04	8.55	6.15	2.75	1.96	1.37

Appendix B – Lexical characteristics from Experiment 1. All experimental conditions were matched in lemma frequency, surface frequency, number of letters, number of phonemes, number of syllables, OLD20, and PLD20.

# Appendix C

## Experiment 2

Present/1pl							
acceptons	approchons	décidons	espérons	gaspillons	luttons	prêtons	renouons
acheminons	aspirons	désirons	évitons	glissons	manquons	promenons	respectons
achetons	attirons	dévorons	évoquons	grimpons	mêlons	proposons	retournons
achevons	avouons	échappons	exagérons	habillons	montrons	racontons	soupirons
activons	calmons	éclatons	existons	ignorons	occupons	ramenons	supportons
adressons	comptons	embarquons	expliquons	imitons	opposons	rassurons	toussons
affrontons	contentons	emportons	félicitons	insistons	penchons	réclamons	traitons
aidons	continuons	empruntons	fermons	invitons	possédons	refusons	trinquons
ajoutons	créons	enjambons	fumons	libérons	préférons	relevons	versons
apportons	creusons	enterrons	gagnons	livrons	préparons	remontons	voguons
Present/2pl							
abandonnez	bousculez	dessinez	espérez	manquez	précipitez	reniflez	souhaitez
abîmez	brûlez	doutez	évacuez	marquez	profitez	renoncez	supposez
accusez	caressez	dressez	évitez	marrez	promenez	rentrez	témoignez
adorez	cessez	échappez	fatiguez	mélangez	prononcez	repassez	tourmentez
annoncez	commandez	éloignez	flanquez	montrez	propagez	reprochez	tracez
approuvez	considérez	emmenez	foncez	nommez	proposez	respirez	travaillez
assimilez	contribuez	emportez	glissez	occupez	rappliquez	retournez	traversez
attaquez	crevez	enfermez	hésitez	partagez	rapprochez	séchez	troublez
attardez	décidez	engagez	ignorez	plongez	refusez	séparez	utilisez
bougez	déshonorez	épousez	insultez	poussez	remontez	sifflez	veillez

## ImpPast/1pl

abîmions	cachions	devinions	évitions	hochions	nommions	priions	répétions
achevions	chantions	dñions	explorions	hurlions	obstinions	profitions	réservations
affichions	collions	disputions	extasions	ignorions	oppositions	projections	roulions
allumions	couchions	écartions	figurions	imaginions	osions	promenions	sautions
apportions	crions	éloignons	formions	invitions	oublions	racontions	scrutions
apprêtions	déchirions	emportions	frôlions	livrions	oublions	regagnions	secouions
arpentions	décidions	enfilions	gardions	manquions	plantions	rejetions	serrions
arrosions	déjeunions	entourions	grimpions	mariions	pleurions	remontions	supplions
assurions	dérobions	éprouvions	habitions	montrions	possédions	rentrions	traitions
brisions	désirions	éveillions	hésitions	moquions	préparions	repassions	trompions

## ImpPast/2pl

acceptiez	cessiez	désiriez	étudiez	ignoriez	mêliez	racontiez	retournez
achetiez	changiez	détestiez	évitiez	imaginiez	méritiez	raisonniez	rêviez
aidiez	charriez	doutiez	existiez	imposiez	montriez	rappelliez	risquiez
ajoutiez	comptiez	éclairiez	expliquiez	indiquiez	moquiez	réclamiez	sacrifiez
amusiez	condamniez	emmeniez	fermiez	invitez	multipliez	rectifiez	signiez
approuviez	confiez	emportiez	filiez	jugiez	pleuriez	refusiez	souhaitiez
assistiez	couchiez	enleviez	fumiez	justifiez	pratiquiez	regrettiez	tâtiez
attachiez	débarquiez	enviez	gardiez	mangiez	préfériez	remarquiez	tentiez
attiriez	décidiez	épousiez	habitez	manquiez	présentiez	rentriez	utilisiez
cédiez	demeuriez	espériez	humiliez	méfiez	promeniez	répétiez	vérifiez

## Appendix D

Tense	Agr.	LemFreq	Surface	Letter	Phoneme	Syllable	OLD20	PLD20
Present	1pl	102.88	0.57	8.35	5.60	2.74	2.11	1.46
	2pl	107.28	0.82	8.03	5.81	2.81	2.05	1.53
Imp. Past	1pl	105.61	0.58	8.96	6.16	2.69	2.33	1.83
	2pl	110.88	0.78	8.13	6.23	2.70	2.18	1.80

Appendix D – Lexical characteristics from Experiment 2. All experimental conditions were matched in lemma frequency, surface frequency, number of letters, number of phonemes, number of syllables, OLD20 and PLD20.

## Appendix E

In what follows, it is shown the nine mixed-effect models analyzed, where: lmerB is the simplest model presented in the general analysis in the article, lmerH is the best multivariate fitted model presented in the article, and lmerE is more complex multivariate model presented below. Tense (indicative present vs. indicative imperfect past) and Agreement (1st plural vs. 2nd plural) are factorial variables; and LemmaFreq, SurfFreq, Letters, Phonemes, Syllables, OLD20, and PLD20 are numerical variables drawn from the French corpus *Lexique 3* (New et al., 2004):

### Mixed-effect models:

- A.  $\text{lmerA} <- \text{lmer}(-1000 * 1/\text{RT} \sim \text{Tense} + \text{Agreement} + (1|\text{Participant}) + (1|\text{Target}), \text{data})$
- B.  $\text{lmerB} <- \text{lmer}(-1000 * 1/\text{RT} \sim \text{Tense} * \text{Agreement} + (1|\text{Participant}) + (1|\text{Target}), \text{data})$
- C.  $\text{lmerC} <- \text{lmer}(-1000 * 1/\text{RT} \sim \text{Tense} + \text{Agreement} + \text{LemmaFreq} + \text{SurfFreq} + \text{Letters} + \text{Phonemes} + \text{Syllables} + \text{OLD20} + \text{PLD20} + (1|\text{Participant}) + (1|\text{Target}), \text{data})$
- D.  $\text{lmerD} <- \text{lmer}(-1000 * 1/\text{RT} \sim \text{Tense} * \text{Agreement} + \text{LemmaFreq} + \text{SurfFreq} + \text{Letters} + \text{Phonemes} + \text{Syllables} + \text{OLD20} + \text{PLD20} + (1|\text{Participant}) + (1|\text{Target}), \text{data})$
- E.  $\text{lmerE} <- \text{lmer}(-1000 * 1/\text{RT} \sim \text{Tense} * \text{Agreement} * (\text{LemmaFreq} + \text{SurfFreq} + \text{Letters} + \text{Phonemes} + \text{Syllables} + \text{OLD20} + \text{PLD20}) + (1|\text{Participant}) + (1|\text{Target}), \text{data})$
- F.  $\text{lmerF} <- \text{lmer}(-1000 * 1/\text{RT} \sim \text{Tense} + \text{Agreement} + \text{LemmaFreq} + \text{SurfFreq} + \text{Letters} + \text{phon} + \text{syll} + (1|\text{Participant}) + (1|\text{Target}), \text{data})$
- G.  $\text{lmerG} <- \text{lmer}(-1000 * 1/\text{RT} \sim \text{Tense} + \text{Agreement} + \text{LemmaFreq} + \text{Letters} + \text{Syllables} + (1|\text{Participant}) + (1|\text{Target}), \text{data})$
- H.  $\text{lmerH} <- \text{lmer}(-1000 * 1/\text{RT} \sim \text{Tense} * \text{Agreement} + \text{LemmaFreq} + \text{Letters} + \text{Syllables} + (1|\text{Participant}) + (1|\text{Target}), \text{data})$
- I.  $\text{lmerI} <- \text{lmer}(-1000 * 1/\text{RT} \sim \text{Tense} * \text{Agreement} * (\text{LemmaFreq} + \text{Letters} + \text{Syllables}) + (1|\text{Participant}) + (1|\text{Target}), \text{data})$

### ANOVA between the different mixed-effect models analyzed:

Model	Df	AIC	BIC	logLik	Chisq	Chi Df	Pr(>Chisq)	
A	6	2808.3	2849.2	-1398.1				
B	7	2802.7	2850.4	-1394.3	7.5717	1	0.005929	**
C	13	2712.0	2800.6	-1343.0	0.1516	2	0.926979	
D	14	2705.2	2800.6	-1338.6	8.7757	1	0.003053	**



E	35	2722.7	2961.2	-1326.4	17.5248	16	0.352449	
F	11	2708.1	2783.1	-1343.1	0.0000	1	1.000000	
G	10	2702.7	2770.8	-1341.3	6.3866	1	0.011499	*
H	9	2707.1	2768.4	-1344.5	99.6255	2	< 2.2e-16	***
I	19	2708.2	2837.7	-1335.1	6.9462	5	0.224671	

\*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$

ANOVA results from the multivariate mixed-effect model including tense, agreement; and numerical lemma frequency, surface frequency, number of letters, number of phonemes, number of syllables, OLD20, and PLD20 as fixed-effect variables (i.e., `lmerE <- lmer(-1000 * 1/RT ~ Tense * Agreement * (LemmaFreq + SurfFreq + Letters + Phonemes + Syllables + OLD20 + PLD20) + (1|Participant) + (1|Target), data)`).

Variables	MSE	NumDF	DenDF	F.value	Pr(>F)	
Tense	1.2612	1	284.79	9.750	0.00384	**
Agreement	0.3212	1	284.79	3.938	0.04818	*
LemmaFreq	4.1569	1	285.48	50.959	7.829e-12	***
SurfFreq	0.1713	1	281.43	2.100	0.14837	
Letters	0.3795	1	283.05	4.652	0.03186	*
Phonemes	0.1347	1	282.53	1.652	0.19980	
Syllables	0.3804	1	282.83	4.663	0.03166	*
OLD20	0.1424	1	282.16	1.746	0.18743	
PLD20	0.0036	1	283.57	0.044	0.83360	
Tense:Agreement	0.0038	1	284.78	0.046	0.83021	
Tense:LemmaFreq	0.0658	1	285.50	0.807	0.36981	
Tense:SurfFreq	0.1604	1	281.45	1.967	0.16189	
Tense:Letters	0.0999	1	283.04	1.225	0.26929	
Tense:Phonemes	0.0098	1	282.52	0.120	0.72959	

---

Tense:Syllables	0.0037	1	282.80	0.045	0.83127
Tense:OLD20	0.0423	1	282.18	0.519	0.47206
Tense:PLD20	0.0268	1	283.56	0.329	0.56690
Agreement:LemmaFreq	0.0182	1	285.49	0.223	0.63738
Agreement:SurfFreq	0.0938	1	281.43	1.150	0.28438
Agreement:Letters	0.0008	1	283.04	0.010	0.91989
Agreement:Phonemes	0.1837	1	282.54	2.252	0.13453
Agreement:Syllables	0.0000	1	282.80	0.000	0.98225
Agreement:OLD20	0.0127	1	282.15	0.156	0.69359
Agreement:PLD20	0.0001	1	283.56	0.001	0.97961
Tense:Agreement:LemmaFreq	0.0271	1	285.47	0.333	0.56461
Tense:Agreement:SurfFreq	0.0000	1	281.43	0.000	0.98374
Tense:Agreement:Letters	0.0984	1	283.03	1.207	0.27292
Tense:Agreement:Phonemes	0.0432	1	282.53	0.530	0.46730
Tense:Agreement:Syllables	0.1691	1	282.80	2.073	0.15105
Tense:Agreement:OLD20	0.0110	1	282.15	0.135	0.71360
Tense:Agreement:PLD20	0.0625	1	283.57	0.766	0.38224

---

\*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$



### 3.4 Study 4: Bilingual Morphological Processing



# Bilingual Morphological Processing on French Verbs: Lexicon Organization and Structure Processing

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## Abstract

Word recognition is mediated by morphological processing where information from different word constituents is extracted, activated, and recombined for word verification. Dual-mechanism models with rule-based and whole word routes are argued to explain the psycholinguistic behavior in late bilinguals, accounting for differences between declarative and procedural memories. Nevertheless, the Romance verbal system presents large consistency in the combinations between stems and inflectional suffixes; thus, bilinguals with the same Romance system in both languages might recycle their L1 mechanisms for L2 processing. In the present study, we investigated L2 French speakers which have Brazilian Portuguese as L1, using two experiments with visual lexical decision task, one with surface and cumulative frequency effects and another with morphological violations in verbal structures. Experiment 1 showed that L2 advanced speakers are more sensitive to the surface and cumulative frequency effects, while beginner speakers are not. Experiment 2 established that late L2 speakers have a similar behavior than native ones when processing different morphological structures of French pseudoverbs with violations. Our results present general differences between beginner and advanced L2 speakers regarding the lexicon organization, but no differences considering the word processing, with a rapid shift from associative to combinatorial processes for verbal processing. We argue that a single-mechanism model can explain our results of word recognition based on morphological processing.

**Keywords:** Psycholinguistics; Bilingualism; Word Recognition; Morphological Processing; Verbal Inflection; Decomposition; Lexical Decision; Frequency Effects; Pseudowords; Cross-Language.

# 1 Introduction

Word recognition is mediated by morphological processing, which is the activation of morphemes as meaningful units for lexical access. It has been considered that late bilinguals would never acquire the same competence than early bilinguals or native speakers because they have a shallow processing in second language (L2) (Clahsen & Felser, 2006). However, it seems that L2 language experience and proficiency, which is always poor compared to native speakers, as also first language (L1) influence in L2 processing is enough to explain the differences of grammar processing between L1 and L2 (Carrasco-Ortiz & Frenck-Mestre, 2014; Frenck-Mestre, 2006). The Declarative/Procedural (DP) model states that late bilinguals first acquire language knowledge through the declarative memory and later, with larger proficiency and competence, transfer these knowledge to the procedural memory (Ullman, 2001c).

This study aims to investigate the morphological processing in late bilinguals who have close L1 and L2. We investigated the morphological processing on French (FR) verbs as L2 by speakers which have Brazilian Portuguese (BP) as L1. French and Portuguese are Romance languages which inherit their verbal system from Latin, presenting a large overlap in the verbal structure and morphosyntactic features. We applied two experiments which were already ran in French native speakers (Gustavo Lopez Estivalet & Meunier, 2015a, 2016c), with visual lexical decision task to track different aspects of the lexicon organization and the processing of verbal structures in the word recognition (Penke, 2006). Our results suggest a single-mechanism model with morphological decomposition for the recognition of all French verbs; verbs are decomposed in stem and inflectional suffixes, then the morphemic representations are activated in the lexicon, and the morphemes are recombined for word verification (Taft, 1979).

Experiment 1 tested the surface and cumulative frequency effects on French verbs (Gustavo Lopez Estivalet & Meunier, 2015a) and Experiment 2 investigated the morphological decomposition and morphemic activation on French pseudoverbs with morphological violations (Gustavo Lopez Estivalet & Meunier, 2016c). Late bilinguals

present different grammar processing (Clahsen & Felser, 2006), language behavior (Jonathan Grainger & Dijkstra, 1992), and neural structure (Perani & Abutalebi, 2005) than native speakers and early bilinguals, thus, our objective was not to replicate the results found in the native speakers of French, but analyze the data by itself and compare the bilinguals' results to the native speakers.

## 1.1 Morphological Models

We can differentiate between search and interactive-activation models, as well as between single- and double-mechanism models. Manelis and Tharp (1977) proposed the Whole Word (WW) model based on the Full-Entry Hypothesis (Jackendoff, 1975); alternatively, Parallel Distributed Processing (PDP) models (D. E. Rumelhart & McClelland, 1986) propose associative-interactive networks between phonological, orthographic, and semantic information in hidden units. From a symbolic manipulation perspective, Taft (1979) proposed the Obligatory Decomposition (OD) model, where words are decomposed for lexical access.

By combining both kinds of word processing, dual-mechanism models consider one route for the associative wholeword access and another route for the rule-based computations. The Augmented Addressed Morphology (AAM) model (Caramazza et al., 1988) proposes that high-frequency, non-transparent, and known words are accessed by the whole word route, while low-frequency, transparent, and unknown words are recognized by the combinatorial route; the Parallel Dual-Route (PDR) model (Baayen et al., 1997) predicts the parallel activation of both routes, where the fastest wins for lexical activation; the Word and Rules (W&R) model, supported by the DP model (Pinker & Ullman, 2002b), proposes a procedural combinatorial route for regular words and a declarative associative route for irregular ones. Afterwards, Allen and Badecker (2002) propose a two level (TL) model where constituents from complex words are firstly activated in the lexeme level and subsequently this forms activate the lemma level; in the same line, de Diego Balaguer et al. (2006) present a model where lexical stems and functional suffixes are processed by different neural circuits. Finally, the Minimalist Morphology (MM) model (Wunderlich & Fabri, 1995) proposes whole word entries with post-lexical morphological processing based on a full symbolic productive route and another hierarchical semi-structured route.



Besides the discussions about the functioning of the morphological processing, there is no general consensus in how inflection is processed by native speakers (Marantz, 2013b). Turning to L2 later speakers, the contradictory and complex results blur the functioning of these models (Green, De Bot, & Huebner, 1993), but allow a better understanding of the L2 morphological acquisition and the interaction between L1 and L2 in the grammar system and mental lexicon organization.

## 1.2 French and Portuguese Verbal Morphology

French and Portuguese are Romance languages developed from Latin during the Middle Age. Both languages are descendants from the Gallo-Iberian family, where French was inherited from Gallic and Portuguese from Iberian families. BP evolved from European Portuguese in the 16th century, presenting differences in syntax, orthography, phonology, prosody, semantics, and borrows from Amerindian languages. French and Portuguese are inflectional languages with rich morphology, where verbal inflection is described as a stem (v), formed by the root ( $\sqrt{\text{ }}$ ) and the theme vowel (Th), merged with a tense node, formed by the tense suffix (T) and the agreement suffix (Agr), according to  $[[[\sqrt{\text{ }}][\text{Th}]\text{v}][[\text{T}][\text{Agr}]\text{T}]\text{TP}]$ , adapted from (Halle & Marantz, 1994) (e.g., French:  $[[[\text{aim}]\sqrt{\text{ }}[\text{e}]\text{Th}]\text{v}][[\text{r}]\text{T}[\text{ons}]\text{Agr}]\text{T}]\text{TP}$ , BP:  $[[[\text{am}]\sqrt{\text{ }}[\text{a}]\text{Th}]\text{v}][[\text{re}]\text{T}[\text{mos}]\text{Agr}]\text{T}]\text{TP}$  ‘we will love’).

Considering cross-linguistic differences between French and BP, Estivalet and Margotti (2014) presented a comparative analysis on the inflectional suffixes and verbal formation in both languages, concluding that there is a large and consistent formal overlap between both verbal inflectional systems. More than the inflectional system correspondence, both languages also present large similarity in stem morphophonology and allomorphy (e.g., FR: *adorons/adore* BP: *adoramos/adoro* ‘we adore/I adore’, FR: *disons/dit* BP: *dizemos/digo* ‘we say/I say’). Moreover, these systems exhibit large syncretism in many morphemes. Moving to a more abstract analysis of the morphosyntactic features expressed by the productive inflectional suffixes in French and Portuguese, and considering the feature underspecification hypothesis, we reduced the clusters available and represented each inflectional suffix with only its positive morphosyntactic features (Penke et al., 2004), as shown in Table 1 for the principal tenses in French and Portuguese (the complete analysis is presented in Appendix A).

Node	Tense						Agreement																		
	I		II		III		IV		V		VI		VII		VIII		IX		X		XI		XII		
Suffix.	FR	BP	FR	BP	FR	BP	FR	BP	FR	BP	FR	BP	FR	BP	FR	BP	FR	BP	FR	BP	FR	BP	FR	BP	
Lang.	ai	va	i	a	r	r	s	s	ai	ei	as	ás	t	u	a	á	ons	mos	ez	is	ent	m	ont	ão	
Feat.																									
Tense	Imp.	+	+	+	+																				
	Fut.					+	+		+	+					+								+	+	
	Cond.	+		+		+	+																		
Person	1			+			+		+	+						+	+								
	2			+			+	+			+	+							+	+					
	3												+	+	+	+						+	+	+	+
Number	Sg						+	+	+	+	+	+	+	+	+										
	Pl			+												+	+	+	+	+	+	+	+	+	

Table 1 – French and Portuguese tense and agreement suffixes with underspecified and only positive morphosyntactic features. Grey features are from different morphosyntactic nodes.

Default morphemes are no feature marked: a) class: 1st, b) mood: indicative, c) tense: present, d) person: 3rd, e) number: singular. We remark the high similarities in the FR/BP suffixal forms and morphosyntactic features, with the agreement suffixes showing higher overlap and regularity than the tense ones. The future and conditional tenses, and the plural agreement morphemes are the most regular and similar through both verbal systems. While the indicative simple past and subjunctive imperfect past tenses are largely used in Portuguese, they are obsolete tenses in French, being substituted by the *passé composé* and subjunctive present, respectively, which have different employments in BP (Gustavo Lopez Estivalet & Margotti, 2014; Kilani-Schoch & Dressler, 2005).

In Table 1, one can observe that a series of inflectional suffixes expressing specific morphosyntactic features, if we reverse this logic, we have a series of morphosyntactic features expressed by specific morphemes (Halle & Marantz, 1994). Then, there is more than just the phonological/orthographic resemblance between the inflectional suffixes in French and Portuguese, there is a large overlap in the morphosyntactic features activated by the inflectional suffixes, allowing a direct mapping from the Portuguese verbal system to the French one in a deep and abstract level of representations and processing.

### 1.3 Bilingual Processing

L1 and L2 processing differ in four main factors: 1) relevant grammatical knowledge, 2) influence from the L1, 3) cognitive resource limitation, and 4) neural maturation (Clahsen & Felser, 2006). Early and late bilinguals can be distinguished in function of the age they

acquire their languages; the critical period for L1 acquisition is considered around seven years old and for L2 around 12 years old, however, the critical period and the neuroplasticity that underline language acquisition has been widely discussed (Friederici et al., 2002; Perani & Abutalebi, 2005). Importantly, while early bilinguals acquire their languages during babyhood through natural and massive stimulation, and communication and task requirements for all purposes; late bilinguals acquire their L2 during adulthood through artificial and poor stimulation, in language courses, explicit instruction, and non-required purposes.

Thus, native and early bilingual speakers unconsciously encode productive procedures in morphological acquisition, in contrast, late bilinguals explicitly acquire declarative knowledge about language. Ullman (2001b) propose that linguistic forms which depend upon procedural memory in L1 might be largely dependent upon declarative memory in L2, and a shift from declarative to procedural memory is expected according to the L2 exposition and proficiency.

Imaging and lesion studies have not provided evidence for neuronal separation between L1 and L2, on the contrary, Perani and Abutalebi (2005) showed that bilinguals recruit at a comparable level areas associated to grammatical tasks in L1 and L2 (i.e., Broca's regions and basal ganglia). Additional activation for L2 in extending areas subserving L1 grammar was found only in bilinguals with low proficiency or late acquisition. Hernandez, Li, and MacWhinney (2005, p.222) complement the computational explanation for age-of-acquisition effects, "because the bilingual child retains greater plasticity and faces somewhat lesser L1 entrenchment, the model predicts a slow but continual reorganization of lexical space. For the young adult, on the other hand, movement on the lexical map may be no longer possible".

In this sense, there should be a large transfer and interference of lexical and grammatical knowledge between L1 and L2, especially between closer typological languages. We propose three basic mechanisms involved in the cross-linguistic interaction and L1 knowledge recycling for L2 acquisition and processing: 1) L1 rules which can be generalized in L2, 2) L1 rules which have to be inhibited in L2, and 3) L2 rules which have to be acquired. For example, BP speakers as L1 which have French as L2 1) can generalize the use of [-ons]<sub>FR:1pl</sub> for [-mos]<sub>BP:1pl</sub>, 2) have to inhibit the use of the indicative simple past and subjunctive imperfect past tenses, and 3) have to acquire the allomorphy between [-ai-]<sub>imp, sg/3pl</sub>~[-i-]<sub>imp, 1pl/2pl</sub> for the French indicative imperfect past tense. Estivalet and Mota (2010) found that native speakers of BP which have French as L2 have significantly larger working memory capacity than those which have English as L2, relying their findings in the

interaction and recycling mechanisms between L1 and L2 in lexical overlap and stem allomorphic constraints.

Grainger and Dijkstra (1992) investigated two hypotheses in the bilingual lexicon, the language tag and the language network based on serial search and interactive-activation models. They observe that language decision latencies in English/French bilinguals were slower than lexical decision latencies, suggesting that there is no language tag activation for lexical decisions and the latter is prior than the former. They proposed the Bilingual Interactive-Activation model (BIA) where language decision can be made once the lexical representation is isolated.

Further, Dijkstra and van Heuven (2002) implemented the BIA+ which adds phonological and semantic lexical representations to the available orthographic ones, and assigns a different role to the language-nodes. Interestingly, words from different languages seem to compete during recognition, that is, the recognition of a word in one language is affected by word candidates in other languages, supporting the assumption of a shared bilingual lexicon (Dijkstra, 2007).

Regarding the experiments applied in the present study, frequency effects have not been largely explored in late bilinguals, and it is an open question whether their lexicon organization deviates from native speakers and corpora norms (Lehtonen & Laine, 2003). Pseudowords provide an interesting environment for the investigation of morphological processing in L2 because they avoid frequency and semantic effects (Caramazza et al., 1988). Our aim with Experiment 1 was to verify the lexicon organization in beginner and advanced bilinguals of French as L2 in function of the frequency norms. We predict to find differences between beginner and advanced bilinguals, where the latter is in line with native speakers, and the former present only surface frequency effects based on whole word access in the declarative memory. Experiment 2 had the objective to identify differences between beginner and advanced speakers in the processing of different violation in French verbal structure. We predict to find differences between beginner and advanced speakers in the verb types containing only stem and inexistent but morphologically legal forms.

Concerning the results in native speakers already published, Experiment 1 presented cumulative frequency effects in fully regular and irregular verbs in both high and low surface frequencies, suggesting that fully regular verbs are fully decomposed for lexical access and that irregular verbs have different but linked representations of the allomorphic stems. Morphophonological verbs did not present any effect of cumulative frequency, but in a *post-*

*hoc* analysis, the effects of total cumulative frequency became clear, supporting the idea that morphophonological verbs have abstract underlined phonological representations (Gustavo Lopez Estivalet & Meunier, 2015a). Experiment 2 in native speakers showed no differences between MI and OB, and between EML and OS verb types, but significant differences between OB and EML, and between OS and IML verb types. Also, there were significant differences in the number of inflectional suffixes in OS and EML verb types (Gustavo Lopez Estivalet & Meunier, 2016c).

## 2 Method

### 2.1 Experiment 1: Surface and Cumulative Frequencies

#### 2.1.1 Participants

A total of 20 adult speakers of BP as L1 and French as L2 between the ages of 20 and 32 years old ( $M = 25.9$  years old, 11 women) took part in Experiments 1 and 2. Participants had between 2 to 14 years of contact with French as L2 ( $M = 5.9$  years). Most part of participants learnt English as L2 in the high school (i.e., from 14 to 17 years), and later started to learn French. All participants were right-handed, had normal hearing, normal vision or corrected by glasses or contact lenses, and had no history of cognitive or language disorders. Experiments 1 and 2 were performed in one session, with a break between them, in counterbalanced order between participants and lists in a Latin square. Participants did not know the research purposes and gave written consent to participate in the experiment as volunteers.

#### 2.1.2 Materials and Design

Experiment 1 used the same materials, design, and procedure than Estivalet and Meunier (2015a). Participants performed a lexical decision task in visual modality. We investigated three variables: 1) verb type: a) fully regular (e.g., *parlons/aiment* ‘we speak/they love’), b) morphophonological *e/ε* with orthographic mark (e.g., *appelons/appellent* ‘we call/they call’), c) morphophonological *o/ɔ* without orthographic mark (e.g., *adorons/adorent* ‘we adore/they adore’), and d) irregular (e.g., *buvons/boivent* ‘we drink/they drink’); 2) surface frequency (high vs. low); and 3) cumulative frequency (high vs. low). We

manipulated four different experimental conditions by verb type: two conditions with high cumulative frequency in high or low surface frequencies, and two conditions with low cumulative frequency in high or low surface frequency. Eighty stem pairs from the four verb types were selected, with 20 pairs for each verb type. For each stem pair, we choose four different forms; for the fully regular verbs, we did not use a stem pair because they have only one stem; we used two different verbs with the same surface frequency. All experimental words were matched in number of letters, number of phonemes, number of syllables, and orthographic neighbors, as calculated by the Orthographic Leveinshtein Distance between the 20 closest words (OLD20) (Yarkoni et al., 2008). A set of 320 pseudowords was added to the 320 experimental words, totalizing 640 stimuli. Pseudowords were constructed by combining non-existent but possible stems to existent verbal suffixes in French. All words and pseudowords were selected and controlled using the French database *Lexique* (New et al., 2004).

### 2.1.3 Procedure

We used the E-Prime® 2.0 Professional (Psychology Software Tools, Inc., Sharpsburg, PA, USA) (Schneider et al., 2012) to construct, apply, and collect experimental data. Each trial followed the sequence: first, a fixation point was displayed on the center of the screen for 500 ms; after, the target word was presented on the center of the screen in lowercases for 2,000 ms or until the participant's response; then, a blank screen was presented as inter-stimuli for 500 ms, and a new trial started with the fixation point. The stimuli were presented on the center of a 15" LCD computer screen, in letter size 18-point Courier New font, in white letters against a black background. RT measure began in the onset of the target screen and finished when the participants performed their responses via a keyboard button. Participants were asked to perform a visual lexical decision task as quickly and accurately as possible using a computer keyboard with the right hand over the 'green' button for words and the left hand over the 'red' button for pseudowords. The experiment started with an instructional screen followed by a practice phase with eight stimuli, one break was provided in the middle of the experiment. The entire experiment lasted approximately 22 min.

### 2.1.4 Results

Only experimental items were analyzed. Responses faster than 300 ms and slower than 1,900 ms were considered out of task and removed (2.39%); two participants were excluded because they had error rates higher than 25% (9.96%); two experimental stimuli (i.e., *nomment* ‘you<sub>pl</sub> name’ and *vailent* ‘you<sub>pl</sub> worth’) were removed because they had error rates higher than 60% (.92%). There were 12.61% of incorrect responses that were removed for the RT analysis.

For the proficiency factor, we equally divided the 18 remaining participants in two groups of French proficiency (beginners vs. advanced) determined by their times of French exposition, i.e., beginners (N = 9, M = 2.9 years) and advanced (N = 9, M = 9.9 years); to support this proficiency division, we verified significant differences between both groups through one-tail t-tests in proficiency ( $t(8) = 6.881, p < .001$ ), error rate (i.e., beginner: 16.52%, advanced: 8.78%) ( $t(8) = 2.713, p < .01$ ), as also a by-participant Pearson’s correlation between proficiency and error rate ( $r = -.609, t(16) = -3.072, p < .01$ ) (McNamara, 2006).

The data were analyzed using two mixed-effects models (Baayen et al., 2008), one with the normalized RTs (i.e.,  $1/RT * -1,000$ ) as the dependent variable, participants and targets as random variables, and verb type, surface frequency, cumulative frequency, and proficiency as fixed-effect variables; and another model with the logit ACC as the depend variable and binomial family specification. Overall RT means and standard deviations (SD) are shown in Table 2.

The analysis of variance (ANOVA) in the RT mixed-effects model shows significant effects of verb type ( $F(3,299) = 3.013, p < .05$ ) and surface frequency ( $F(1,299) = 7.679, p < .01$ ), but no effect of cumulative frequency ( $F(1,299) = .859, p = .355$ ) or proficiency ( $F(1,16) = 1.292, p = .272$ ). Importantly, there is a significant interaction between proficiency and cumulative frequency ( $F(1,4577) = 19.384, p < .001$ ) and a significant interaction between proficiency and surface frequency ( $F(1,4577) = 8.193, p < .01$ ), but no other interaction ( $F_s < 1, p_s > .1$ ).

Moving to the planned comparisons of the effects of surface and cumulative frequencies in beginner and advanced bilinguals, we present only the significant results. In the beginner speakers, there is a significant total cumulative frequency effect in morphophonological e/ε verbs with low surface frequency ( $t(354) = 3.763, p < .001$ ) and high surface frequency ( $t(353) = 2.505, p < .05$ ). In morphophonological o/ɔ verbs, there is a significant total

cumulative frequency effect in forms with low surface frequency ( $t(357) = 2.083, p < .05$ ). In the advanced speakers, there is a significant surface frequency effect in fully regular verbs with low cumulative frequency ( $t(330) = 2.354, p < .05$ ). In the morphophonological e/ε verbs, there is a significant total cumulative frequency effect in forms with low surface frequency ( $t(343) = 2.455, p < .05$ ), and a significant surface frequency effect in forms with low cumulative frequency ( $t(345) = 1.997, p < .05$ ). In the morphophonological o/ɔ verbs, there is a significant surface frequency effect in forms with low total cumulative frequency ( $t(346) = 3.391, p < .001$ ), and a significant surface frequency effect in forms with low cumulative frequency ( $t(345) = 1.997, p < .05$ ) and high cumulative frequency ( $t(335) = 2.162, p < .05$ ). In the irregular verbs, there is a significant surface frequency effect in forms with low cumulative frequency ( $t(337) = 2.554, p < .05$ ), as also a significant cumulative frequency effect in forms with high surface frequency ( $t(338) = 2.306, p < .05$ ).

		High Surface Frequency		Low Surface Frequency	
Profic.	Verb Types	High Cum.	Low Cum.	High Cum.	Low Cum.
Beginner	a) Fully Regular	911(260)	947(257)	948(287)	948(267)
	b) Morpho. e/ε	956(288)	977(303)	922(254)	1054(326)
	c) Morpho. o/ɔ	960(292)	915(273)	954(272)	977(280)
	d) Irregular	1021(321)	993(298)	968(274)	1028(295)
Advanced	a) Fully Regular	834(292)	860(290)	876(285)	879(329)
	b) Morpho. e/ε	872(310)	880(306)	857(302)	925(315)
	c) Morpho. o/ɔ	842(285)	866(317)	894(317)	937(350)
	d) Irregular	826(277)	892(319)	901(319)	982(348)

Table 2 - RT means and SDs by verb type, surface frequency, cumulative frequency, and proficiency.

The analysis of deviance in the error rate mixed-effects model showed significant differences for verb type ( $\chi^2(3, N = 18) = 10.986, p < .05$ ), total cumulative frequency ( $\chi^2(1, N = 18) = 17.712, p < .001$ ), and proficiency ( $\chi^2(1, N = 18) = 8.012, p < .01$ ), but no significant interactions between these variables ( $ps > .1$ ). The error rate means are shown in Table 3.



		High Surface Frequency		Low Surface Frequency	
Profic.	Verb Types	High Cum.	Low Cum.	High Cum.	Low Cum.
Beginner	a) Fully Regular	.394	.322	.394	.287
	b) Morpho. e/ε	.681	.431	.592	.646
	c) Morpho. o/ɔ	.592	.466	.789	.556
	d) Irregular	.502	.646	.431	.448
Advanced	a) Fully Regular	.197	.287	.215	.215
	b) Morpho. e/ε	.215	.358	.378	.358
	c) Morpho. o/ɔ	.233	.215	.466	.322
	d) Irregular	.126	.322	.631	.089

Table 3 – Error rate means by verb type, surface frequency, cumulative frequency, and proficiency.

### 2.1.5 Discussion

Experiment 1 showed RT significant differences in surface frequency and verb type, with longer RTs for verbal forms with low surface frequency and for irregular verbs; also, the results showed significant interactions between proficiency and surface frequency, and between proficiency and cumulative frequency, indicating that proficiency modulates the results from these predictors. The surface and cumulative frequency effects are mainly significant in advanced bilinguals, while beginner bilinguals present significant differences only in the total cumulative frequency in morphophonological verbs.

The results show that irregular verbs present the slowest RTs, contradicting dual-mechanism models which state that irregulars are quickly recognized by the whole word route, as the W&R (Pinker & Ullman, 2002b). This suggests that irregular verbs are also recognized by the combinatorial route, but present slower RTs due to allomorphic processes (Orsolini & Marslen-Wilson, 1997).

Unexpected, there are surface frequency effects only in advanced speakers. The surface frequency is a robust effect in psycholinguistics, where more frequent words are recognized faster than less frequent ones. These results suggest that advanced speakers with more proficiency and competence present a mental lexicon organization significantly different from

beginner speakers, and more in line with the corpora frequency norms (Hernandez et al., 2005).

We found significant differences in cumulative frequency in irregular verbs in advanced speakers, supporting that they might have separated, albeit linked, stem allomorphic representations in the mental lexicon. In the fully regular verbs, there is only a significant effect of surface frequency, it is possible that L2 speakers, as for the irregular verbs, have actually different stem representations, one being only the roots (e.g., [*jou*]ons ‘we play’) and another being the root combined with the theme vowel (e.g., [*joue*]s ‘you<sub>sg</sub> speak’) (Aronoff, 2012; Say & Clahsen, 2002; Veríssimo & Clahsen, 2009). Perhaps the L1-BP/L2-French speakers tested did not acquire the full decomposition rule as French native speakers because in Portuguese most part of stems are a clear combination of a root with a theme vowel (Gustavo Lopez Estivalet & Margotti, 2014).

These results suggest that L2 advanced speakers are not faster than beginners, however, beginner and advanced L2 speakers present differences in the mental lexicon organization in function of surface and cumulative frequency norms. Advanced speakers had more stimulation and interaction in L2, presenting a pattern of behavior towards native speakers (Costa & Sebastián-Gallés, 2014), while beginners had restricted L2 stimulation and frequency norms are bad predictors for the lexicon organization. This pattern is clarified by the error rate results in proficiency, confirming that advanced speakers significantly know more words than beginners.

Comparing to the native speakers’ study, beginner and advanced speakers of French as L2 presented differences from native speakers. While the native speakers presented robust effects in the surface and cumulative frequencies in fully regular and irregular verbs, advanced bilinguals present only some significant effects towards the native speakers, while beginner bilinguals present a different pattern than native speakers and advanced bilinguals, with no reliable significant differences.

As expected, surface and cumulative frequencies are too abstract and inconsistent to the way that late bilinguals acquire and are exposed to L2 (Nation, De Bot, & Huebner, 1993). Therefore, Experiment 2 aims to overcome these frequency difficulties and limitations, exploring effects of morphological hierarchical structures in pseudoverbs (Gustavo Lopez Estivalet & Meunier, 2016c).

## 2.2 Experiment 2: French Pseudoverbs

### 2.2.1 Participants

Experiment 2 participants were the same than Experiment 1. Participants did not know the research purposes and gave written consent to participate in the experiment as volunteers.

### 2.2.2 Materials, Design, and Procedure

Experiment 2 used the same materials, design, and procedure than Estivalet and Meunier (2016). Participants performed a visual lexical decision task. We tested two variables, 1) verb type: a) morphologically illegal (MI) (e.g., *\*abrou*), b) only base (OB) (e.g., *\*[aim]ou*), c) only suffix (OS) (e.g., *\*abr[ons]*), d) inexistent but morphologically legal (IML) (e.g., *\*[aim][ir]*), and e) existent and morphologically legal (EML) (e.g., *[[aim][ons]* ‘we love’; and 2) number of verbal inflectional suffixes: one inflectional suffix Agr (e.g., *aim[ons]* ‘we love’) vs. two inflectional suffixes T and Agr (e.g., *aim[i][ons]* ‘we loved’). Two hundred and fifty words were selected as experimental items, being 50 words for each verb type. The pseudowords were initially created using the pseudoword toolbox from the French database *Lexique* (New et al., 2004) and were then manipulated to fit the different verb types of interest. We controlled the number of letters, number of phonemes, number of syllables, and OLD20 (Yarkoni et al., 2008). A set of 250 fillers was inserted to counterbalance the responses, being 200 words and 50 pseudowords, totalizing 500 stimuli. The experiment started with a screen of instructions followed by 10 practice stimuli, being held in around 28 minutes. Experiment 2 procedure was the same than Experiment 1.

### 2.2.3 Results

Only experimental items were analyzed. Responses faster than 300 ms and slower than 1,900 ms were considered out of task and discarded (2.96%); two experimental stimuli (i.e., *\*mouri* and *\*poudrent*) were removed because they had error rate higher than 60% (.21%). There were 19.63% of incorrect answers that were removed for the RT analysis. Overall RTs and significant differences are shown in Figure 1.

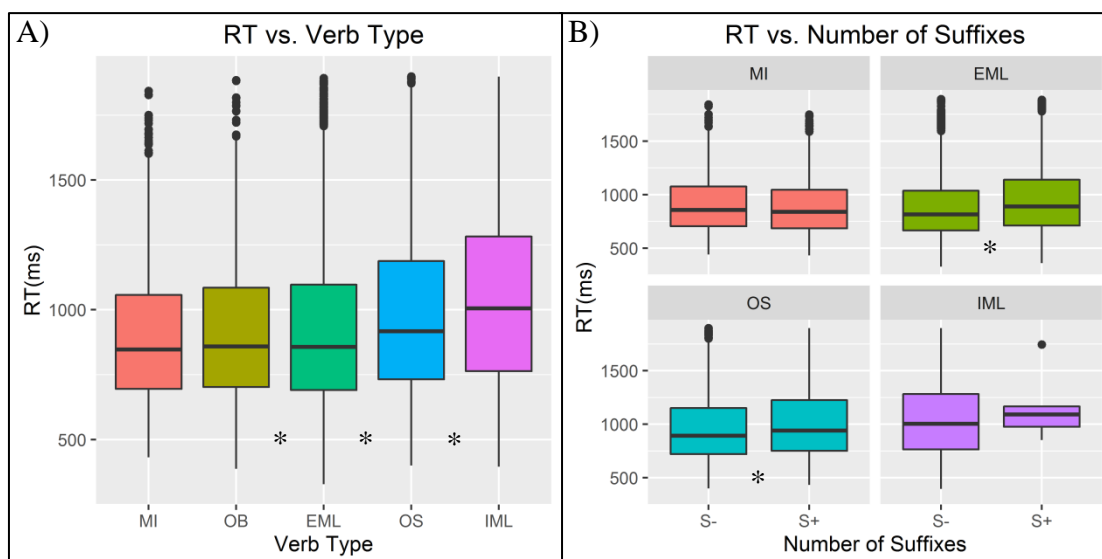


Figure 1 - RTs by verb type and number of suffixes. A) RTs by verb type. B) RTs by number of suffixes. S- for one suffix and S+ for two suffixes.

As in Experiment 1, we equally divided the 20 participants in two groups of L2 French proficiency (beginner vs. advanced) determined by time of French exposition (i.e., beginners:  $N = 10$ ,  $M = 2.9$  years; advanced:  $N = 10$ ,  $M = 9.9$  years), and verified differences by proficiency ( $t(9) = 8.281$ ,  $p < .001$ ), error rate (i.e., beginner: 24.33%, advanced: 14.02%) ( $t(9) = 2.954$ ,  $p < .05$ ), and the correlation between proficiency and error rate ( $r = -.509$ ,  $t(18) = -2.513$ ,  $p < .05$ ) (McNamara, 2006).

The data were analyzed using two mixed-effects models (Baayen et al., 2008), one with normalized RTs (i.e.,  $1/RT * -1,000$ ) as the dependent variable, participants and targets as random variables, and verb type, number of suffixes, and proficiency as fixed-effect variables; and another model with logit ACC as the dependent variable and binomial family specification.

The ANOVA in the RT mixed-effects model shows significant effects of verb type ( $F(4,1043) = 31.118$ ,  $p < .001$ ), number of suffixes ( $F(1,2656) = 4.466$ ,  $p < .05$ ), but no effect of proficiency ( $F(1,17) = .557$ ,  $p = .465$ ); there is also a significant interaction between verb type and number of suffixes ( $F(3,1129) = 4.101$ ,  $p < .01$ ), but no other significant interaction ( $F_s < 1$ ,  $p_s > .1$ ). Mining the planned comparisons, MI and IML showed no difference in the number of suffixes (respectively,  $t(795) = .451$ ,  $p = .652$  and  $t(2737) = 1.486$ ,  $p = .137$ ) while EML and OS showed significant differences in the number of suffixes (respectively  $t(875) =$

7.577,  $p < .001$  and  $t(976) = 4.321$ ,  $p < .001$ ). OB differences in the number of suffixes was not analyzed because it has only a base and no existent suffixes.

MI showed no difference to OB ( $t(800) = .551$ ,  $p = .582$ ), but significant differences to EML ( $t(803) = 1.982$ ,  $p < .05$ ), to OS ( $t(811) = 2.238$ ,  $p < .05$ ), and to IML ( $t(888) = 5.431$ ,  $p < .001$ ). OB presented significant differences to EML ( $t(822) = 3.531$ ,  $p < .001$ ), to OS ( $t(837) = 2.191$ ,  $p < .05$ ), and to IML ( $t(948) = 5.981$ ,  $p < .001$ ). EML showed significant differences to OS ( $t(902) = 8.559$ ,  $p < .001$ ), and to IML ( $t(1038) = 10.494$ ,  $p < .001$ ). OS presented significant differences to IML ( $t(1059) = 5.274$ ,  $p < .001$ ). It becomes clear that it is the EML verbs which yield the interactions between verb type and number of suffixes.

The analysis of deviance in the error rate mixed-effects model showed significant differences in verb type ( $\chi^2(4, N = 20) = 179.975$ ,  $p < .001$ ), number of suffixes ( $\chi^2(1, N = 20) = 16.651$ ,  $p < .001$ ), and proficiency ( $\chi^2(1, N = 20) = 16.523$ ,  $p < .001$ ), as also a significant interaction between proficiency and verb type ( $\chi^2(4, N = 20) = 61.312$ ,  $p < .001$ ), but no other significant interaction ( $ps > .1$ ).

## 2.2.4 Discussion

We found the general Figure 1A RT order: MI = OB < \*EML < \*OS < IML, where ‘less than’ and ‘asterisk’ indicate significant effects of verb type and number of suffixes differences, respectively. OB is decomposed based in the stem information but is immediately rejected because no existent suffix is found. EML and OB verb types are different because the former follows the whole process for word recognition, slowing RTs. Further, EML and OS verb types are different because the latter spend longer time searching for the stem, yielding longer RTs. Finally, IML verb type is different from the other verb types because its inhibitory processes in the later recombination phase for word rejection, slowing RTs (Caramazza et al., 1988; Gustavo Lopez Estivalet & Meunier, 2016c).

This pattern is the same as the one observed for French native speakers (Gustavo Lopez Estivalet & Meunier, 2016c), with one single difference: the significant difference between EML and OS verb types in the present study. Considering the bilingual lexicon, it seems that L2 speakers have few stems stored and can quickly find the stems which they know (EML), however, when they do not find a stem (OS), they still try to interpret the foreign stem and transfer L1 knowledge for its interpretation, yielding significant differences between these verb types (Hernandez et al., 2005).

The effect of the number of suffixes present a similar pattern of results than native speakers (Gustavo Lopez Estivalet & Meunier, 2016c). MI and IML verb types do not present any significant difference in the number of suffixes, while OS and EML verb types do. MI verb type is quickly rejected because of its idiosyncratic form and structure, with no place for word decomposition and morphemic activation; differently, IML verbs have existent morphemes but inexistent combinations of these morphemes, thus, IML verb type is rejected in a later verification of the word through inhibitory processes, slowing their RTs (Baayen et al., 1997) and blurring the number of suffixes effect. Inversely, OS verb type are decomposed and have their existent suffixes activated; independently of the stem crash, the number of suffixes present a significant difference because forms with two suffixes impose an extra computation for word rejection. EML verb type presents the same processes, but a succeeded well-formed lexical recombination and verification (Taft, 1979).

Finally, the error rate analysis is in general agreement with Estivalet and Meunier (2016) results on native speakers, and most important, there was a main significant effect in proficiency and an interaction between proficiency and verb type, suggesting that advanced bilinguals had less errors because they know more words than beginners.

Experiment 2 showed that morphological investigation in bilinguals using pseudowords is fruitful because it is possible to bind frequency effects. It suggests that even beginner bilinguals might decompose verbs based on morphological information. Comparing to the native speakers' results, late bilinguals present almost the same behavior; beside general higher RTs and error rates in bilinguals, the order of RTs and the significant differences in the number of inflectional suffixes to be processed are the same in beginner and advanced bilinguals, and native speakers of French, suggesting that the general morphological structure is equally processed in both populations.

### 3 General Discussion

The present study comprises two experiments which investigate the morphological processing and representation of French verbs in L2 speakers which have BP as L1. Experiment 1 manipulated surface and cumulative frequencies in four verb types (Gustavo Lopez Estivalet & Meunier, 2015a) and Experiment 2 tested five different types of (pseudo)verbs.

The present bilingual results are comparable to the previous native speakers' results in Experiment 2 while Experiment 1 yielded different results than native speakers. We analyzed the difference between L2 French beginner and advanced speakers, and we found a fast shift from associative to combinatorial processing in beginner and advanced bilinguals.

### 3.1 Morphological Processing and Proficiency

Through our present results and large evidence on bilingual proficiency differences (Clahsen & Felser, 2006; Costa & Sebastián-Gallés, 2014; de Diego Balaguer, Sebastián-Gallés, Díaz, & Rodríguez-Fornells, 2005; Dijkstra, 2007; Hernandez et al., 2005; McNamara, 2006; Nation et al., 1993), it becomes clear that advanced bilinguals have a better performance in psycholinguistic experiments than beginner ones. Nevertheless, even if advanced speakers results go towards native's results, late bilinguals still present differences and limitations in morphological processing, lexical representations, and mental lexicon organization (Clahsen & Felser, 2006). Nevertheless, these differences between L1 and L2 speakers can be explained by considering the general low proficiency and language deficit in L2 speakers, as also the influence from L1 (Frenck-Mestre, 2006; Osterhout, McLaughlin, Pitkänen, Frenck-Mestre, & Molinaro, 2006). Thus, even if L2 speakers can have a deep grammatical processing, L2 deficit and L1 interference modulate their behaviours.

It can be observed a systematic difference in the error rate results across experiments and experimental conditions, with advanced speakers presenting on average the half error rates than beginners, and native speakers presenting much fewer than the half error rates than advanced ones. In contrast, RT means do not present differences between beginner and advanced speakers, but a large difference between native speakers and advanced ones (Dijkstra & van Heuven, 2002). We found significant differences in error rates between beginner and advanced speakers and significant correlations between language exposition time and error rates, but no significant RT differences or correlations to proficiency. Importantly, proficiency interacted with the other experimental variables, supporting the idea that proficiency directly affects speakers' performance (Costa & Sebastián-Gallés, 2014).

Experiment 1 did not yield clear results regarding surface and cumulative frequencies differences in L2 French speakers because late bilinguals do not have the same mental lexicon organization than native speakers, as predicted by frequency norms (Lehtonen & Laine, 2003). Even if corpora present rich, valuable, and predictive information for native speakers'

lexical decisions (New et al., 2004), this information does not fit the behavior in late bilinguals and their lexicon organization. Late bilinguals have different language learning and exposition than native speakers, mainly through language courses, didactic material, short, artificial, and no required communication purposes (Hernandez et al., 2005).

While beginners present an unclear pattern of frequency effects, advanced speakers present a pattern towards native speakers' behavior. Advanced speakers were participants living in France for at least four years, being naturally exposed to language frequency norms and required communicative situations, thus, it seems that L2 proficiency tunes corpora frequency norm predictions.

Experiment 2 showed that when frequency and semantic knowledge is partially contoured, different results emerge from the processing of morphological hierarchical structures; there are no differences between beginner and advanced L2 French speakers, and most interesting, their results are in line with the native speakers' pattern, suggesting the same kind of morphological processing for lexical access and word recognition (Perani & Abutalebi, 2005).

We have to keep in mind that adult participants in L1 psycholinguistic experiments have at least 18 years of massive language exposition since babyhood, and late bilinguals in the present experiments had on average three years of language exposition for beginner and nine years for advanced speakers since adulthood. Thus, in native speakers, the mother tongue naturally sculpt, develop, and stimulate neural circuits which become specialized in the processing of specific language parameters; in late bilinguals, the L2 is initially acquired through translation, associative relations to L1, and explicit grammatical knowledge, and later, L2 redundancies are solved and formalized for language processing (Ullman, 2001c).

Our results suggest that this early phase with whole word representation is very short in beginner bilinguals and only holds until the speakers have enough information to proceduralize grammatical redundancies (Ullman, 2001a). Particularly, speakers which have close typological/grammar L1 and L2 might recycle neuronal circuits and mechanisms for word recognition, resulting in a fast shift from declarative to procedural memories.

### 3.2 Frequency and Pseudoword Evidence

Lehtonen and Laine (2003) proposed that while bilinguals explore combinatorial processes in low, median, and high word frequencies, native speakers access high frequency



words directly as whole forms. Our results goes in the same sense for L2 French speakers, where since early stages of language acquisition they explore the combinatorial processes for word recognition.

Proficiency interacted with both surface and cumulative frequencies. However, there was no effect of cumulative frequency in fully regular verbs in advanced speakers, probably because they did not tune their lexical access to corpora frequency norms to yield significant stem frequency differences. There were differences between fully regular and irregular verbs in both beginner and advanced speakers, which could suggest that allomorphic processes in irregular verbs take place, slowing RTs (Allen & Badecker, 2002).

Experiment 2 supports the idea that beginner and advanced speakers can decompose words for lexical access. These results can be directly compared to the native speakers' study, and suggest that when frequency and semantic knowledge are alleviated using pseudowords, pure abstract combinatorial morphological processes are tracked (Caramazza et al., 1988). Only real verbs (EML) presented interactions with the other verb types in the number of suffixes, thus, beginner and advanced speakers behavior in rejecting pseudoverbs and recognizing real words cannot be differentiated (Alvarez, Holcomb, & Grainger, 2003).

### 3.3 Portuguese/French Interface

French 1st regular and 3rd irregular classes of verbs present significant differences in Experiment 1 with the latter yielding longer latencies. These results are different from other Romance languages, as Catalan (de Diego Balaguer et al., 2005), Italian (Say & Clahsen, 2002), and Portuguese (Veríssimo & Clahsen, 2009), which found differences between 1st combinatorial class and 2nd/3rd whole word classes, in agreement to dual-mechanism models such as the W&R/DP (Pinker & Ullman, 2002b) or the MM (Wunderlich & Fabri, 1995). Our results seem to indicate morphological decomposition also for French 3rd class verbs based on the systematic inflectional suffixes, with longer latencies in irregulars as consequences of allomorphic processes.

We remark that in Romance languages, even if there are allomorphic representations or allomorphic rules in the lexical morpheme, mostly in the theme vowel and stems from the 2nd and/or 3rd classes depending on language, verbal inflection almost always present inflectional suffixes in word formation (Orsolini & Marslen-Wilson, 1997). Functional morphemes have to be isolated to have their morphosyntactic features checked and processed, consequently,

roots and stems becomes represented in the mental lexicon. De Diego Balaguer et al. (2006) presented fMRI results which give support to a decompositional model where different neural circuits process stem phonological information from the lexical morpheme and morphosyntactic features from the functional morphemes.

Regarding L1/L2 transfer, we remark that both French and Portuguese have morphophonological processes driven by the prosodic system, thus, these computations can be easily transferred from L1 to L2 since speakers acquire the French prosodic system. Therefore, considering that L1-BP/L2-French speakers already have many circuits developed in their L1, they can largely transfer phonological, orthographic, syntactic, morphological, and semantic knowledge from L1 to L2, and a much more dynamic system for lexical representation and grammatical rule application may emerge (Nation et al., 1993). Beside specific French phonemes (e.g., /y/, /ə/, /œ/), orthography (e.g., <œ>, <è>, <ù>, <y>; diphthongs: <ai> → /ɛ/, <au> | <eau> → /o/, <ph> → /f/, <gn> → /ɲ/, /ɛ/ /\_<ll> | <tt>), and semantic/pragmatic differences (e.g., FR: *émergence* ‘emergence’, BP: *emergência* ‘emergency’; FR: *jouer* ‘to play’, BP: *tocar* ‘to play’), one can consider that speakers already have a large amount of the grammar principles underlined and that speakers transfer linguistic knowledge between L1 and L2.

Finally, we suggest that the late acquisition of an L2 close to the L1 is mediated by a short declarative associative phase in lexical encoding, and since L2 speakers have enough accumulated information in their mental lexicon, there is a shift to procedural combinatorial processes (Ullman, 2001c). These morphological processes become automatic and optimized accordingly to L2 speakers’ proficiency and relation to L1. It is hard to imagine how PDP models could explain and/or simulate L1-to-L2 transfer, L2 competence based on language proficiency, and the fast shift from beginner to advanced speakers without posing language rules and symbolic manipulations.

## 4 Conclusions

In the present study, we presented evidence through two experiments of how French inflected verbs are processed in L2 by speakers which have BP as L1. Beside specific differences between beginner and advanced speakers, it seems that both groups are exploring the same decompositional mechanism for lexical access and word recognition (Lehtonen & Laine, 2003).

Future research should deeper analyze inflection processing through auditory stimuli in French, given that this language present large grapheme-to-phoneme inconsistency. Also, it would be interesting to test proficient late L2 speakers which have at least 18 years of L2 exposition, as compared to the native speakers tested in psycholinguistic experiments.

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# Appendix A

Node	Class	Tense	Agreement
Suffix	I FR BP FR BP FR BP	V ai	IX s
Lang.	II FR BP FR BP FR BP	VI va i a r r	X s ai ei as ás
Feat.	III FR BP FR BP FR BP	VII FR BP FR BP FR BP	XI FR BP FR BP FR BP
Class 1	IV FR BP FR BP FR BP	VIII FR BP FR BP FR BP	XII FR BP FR BP FR BP
Class 2			XIII FR BP FR BP FR BP
Class 3			XIV FR BP FR BP FR BP
Tense Pres.			XV FR BP FR BP FR BP
Imp.			XVI FR BP FR BP FR BP
Perf.			XVII FR BP FR BP FR BP
Fut.			XVIII FR BP FR BP FR BP
Cond.			XIX FR BP FR BP FR BP
Subj. Pres.			XX FR BP FR BP FR BP
Sub. Imp.			
Person 1			
Person 2			
Person 3			
Number Sg			
Number Pl			



## Summary from Studies 3 and 4

Study 3 showed significant differences between French verbal forms with one morphological and two morphological operations, as defined by the number of inflectional suffixes. Experiment 1 showed the morphological operation effect in fully regular verbs from the 1st class and irregular verbs from the 3rd class. The results presented the morphological operation effect in verbal forms with low and high surface frequencies in both regular and irregular verbs. There were also significant effects of surface frequency and verb type, but no interaction between any of these variables, indicating that the effects can be independent.

The surface frequency effects has been interpreted as both the access of whole word forms or the result between the combination of different specific morphemic representations to form a complex word (Baayen, Moscoso del Prado Martín, Schreuder, & Wurm, 2003; Meunier & Segui, 1999b; Taft & Forster, 1975; Taft, 1979). Our results are in line with the latter interpretation in which words are decomposed and accessed by means of their morphological representations, yielding the cumulative frequency effect. Thus, the inflectional suffixes are processed in function of their morphosyntactic features, and are later recombined, yielding the surface frequency effect. Additionally, fully regular verbs were recognized faster than irregular ones, contradicting morphological models which state that irregular words might be accessed faster by the whole word route; we suggest that irregular verbs are recognized slowly because of allomorphic processes or competition in the stem formation.

Experiment 2 refined the protocol and tested specific French verbal forms from the fully regular 1st class in the indicative present and imperfect past, and in the 1st and 2nd plural agreements (i.e., *jouons, jouions, jouez, jouiez* ‘we play, we played, you<sub>pl</sub> play, you<sub>pl</sub> played’). The results showed a significant interaction, with differences between the present and imperfect past tenses in the two agreements, but only a difference between 1st and 2nd plural agreements in the imperfect past tense. These results suggest that the morphological operation effect is an additional effect to the cumulative frequency. Importantly, the results are explained in terms of morphosyntactic features processing, the indicative imperfect past tense present the [-i-] morpheme which activates an extra feature [past] for interpretation, and the 2nd plural agreement [-ez] morpheme seems to be the default plural morpheme, thus, underspecified in the 2nd person, accelerating RTs.

Study 4 applied the experiment from Study 1 and a previous version of the experiment from Study 5 in beginner and advanced speakers of French as L2 which speak BP as L1. It

becomes clear in Experiment 1 that while advanced speakers present a behavior towards native ones, but different from native and beginner speakers, beginner speakers do not present any surface and cumulative frequency effect. Thus, it seems that L2 proficiency tunes the lexicon organization in function of the frequency norms. Experiment 2 showed that beginner and advanced bilinguals performing similarly to native speakers in the processing of verbal structures and formal violations, suggesting that independent of word frequencies, bilinguals which have close L1 and L2, can quickly transfer a large amount of grammatical knowledge and apply rule-based process in morphological processing for word recognition in L2.

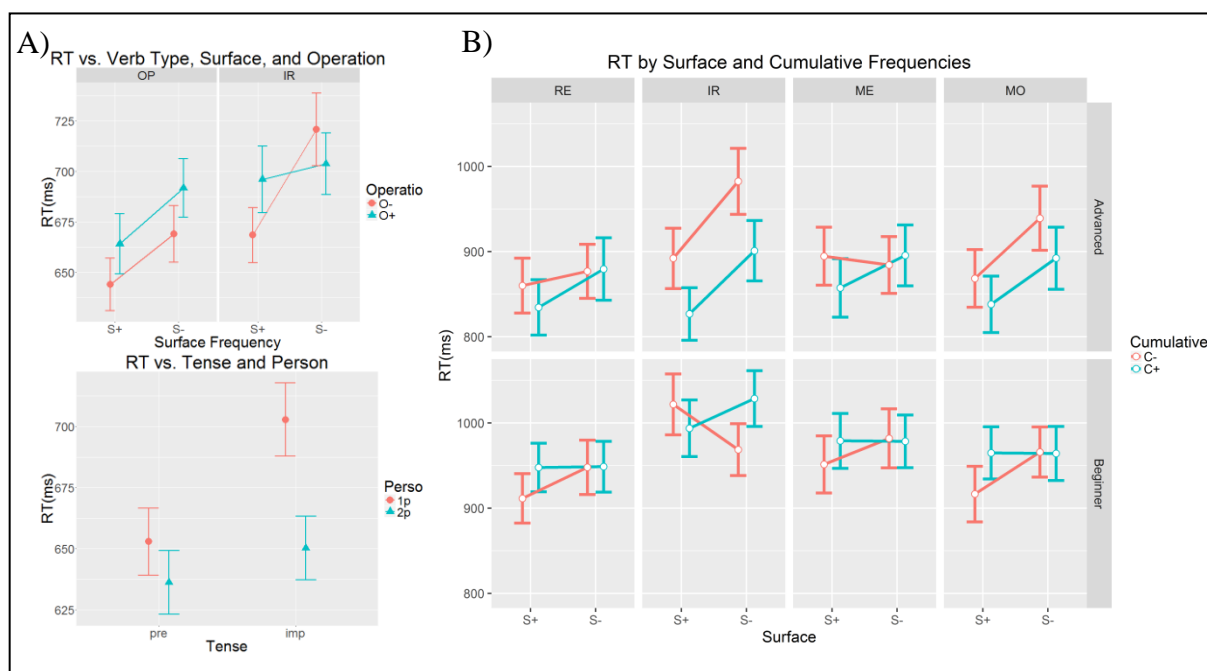


Figure 27 - Summary of results from A) Study 3 and B) Study 4.

Finally, we decided to pursue our investigation in the morphological processing of French inflected verbs for word recognition with the monolingual population. Our aim was to precisely define the time-course of the verbal inflectional processing in single word lexical decision task. Therefore, we developed an experiment with existent morphologically legal (EML: *[[parl][ons]]* ‘we speak’) inflected French verbs as the control condition and four condition of structure and morphological violations, morphologically illegal (MI: *\*barlond*), only base (OB: *\*parlond*), only suffixes (OS: *\*barlons*), and inexistent morphologically illegal (IML: *\*[[parl][ont]]*), and applied this experiment coupled with the EEG acquisition for fine analyses of the word recognition time-course. Therefore, in what follows we present the last Study 5 as a short and ambitious chapter in the investigation of the morphological processing during visual word recognition.

### 3.5 Study 5: Electrocircuiting French Pseudoverbs





# Electrocircuiting French Pseudoverbs: The Time-Course of Verbal Inflection

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## Abstract

Word recognition is essential for language comprehension and a window for understanding word processing and mental representations. In the present study we investigate the morphological processing of words through a lexical decision task on visual modality coupled with electroencephalography. We tested French inflected verbal forms with different morphological violations to identify decomposition, hierarchical structure, morphemic activation, and the time-course of visual recognition of these forms. Five morphological constructions were tested: a) morphologically illegal (*\*barlond*), b) only base (*\*[parl]ond*), c) only suffix (*\*barl[ons]*), d) inexistent but morphologically legal (*\*[parl][ont]*), and e) existent and morphologically legal (*[[parl][ons]* ‘we speak’). We also tested the difference between one or two inflectional suffixes (*parl[ons]* ‘we speak’, *parl[i][ons]* ‘we spoke’). Our results show differences between the different verbal forms. There were effects of the number of inflectional suffixes in only two conditions: only suffix and existent morphologically legal forms. Electrophysiological data indicate differences between verbs and pseudoverbs with only suffix and morphologically illegal in the N1-P2, and specific LAN/N400 and P600 modulations between verbs and inexistent morphologically legal forms. LAN modulations appear between forms with existent and inexistent stem and N400 between forms with or without inflectional suffixes. These results support a single-mechanism model with morphological decomposition and morphemic activation; verbs are early decomposed in

stem and inflectional suffixes, have their lexical and functional morphemes activated, and later these morphemes are recombined for word verification.

**Keywords:** Word Recognition; Morphology; Inflection; Mental Lexicon; Decomposition; Lexical Decision; Pseudoverbs; Word Structure; Time-Course; EEG/ERP.

## 1 Introduction

Word recognition is mediated by morphological processing, where inflected verbs are accessed through combinatorial processes between stem and inflectional suffixes in hierarchical structures for word formation (Marantz, 2016). Electrophysiological studies brought increasing support for this hypothesis, using masked priming tasks (Barber, Domínguez, & de Vega, 2002; Domínguez, de Vega, & Barber, 2004; Lavric, Clapp, & Rastle, 2007; Lavric et al., 2012; Morris & Stockall, 2012; Münte, Say, Clahsen, Schiltz, & Kutas, 1999; Royle et al., 2012; Weyerts, Münte, Smid, & Heinze, 1996) and sentence violation paradigms studies (Coulson, King, & Kutas, 1998; Frenck-Mestre et al., 2008; Leinonen, Brattico, Järvenpää, & Krause, 2008; Leminen et al., 2016; Newman, Ullman, Pancheva, Waligura, & Neville, 2007; Rodriguez-Fornells et al., 2001; Roehm, Bornkessel, Haider, & Schlesewsky, 2005; Roehm, Schlesewsky, Bornkessel, Frisch, & Haider, 2004).

Differently, in the present article we investigated the morphological processing on French inflected verbs in visual word recognition using a single word lexical decision task coupled with electroencephalogram (EEG) (Gross, Say, Kleingers, Clahsen, & F. Münte, 1998; Krott, Baayen, & Hagoort, 2006; Zweig & Pylkkaenen, 2009). Our aim was to track the different morphological processes and the time-course of word decomposition, activation, and verification in visual word recognition (Lavric et al., 2012; Pylkkänen & Marantz, 2003; Rastle et al., 2000; Stockall et al., 2004; Taft, 1979).

On one hand, the Single Route (SR) model has shown magnetoencephalography (MEG) evidence that all complex words are decomposed for lexical access. The SR is based on the Distributed Morphology, which divides the mental lexicon in semantic and morphosyntactic features, vocabulary items, and encyclopedia (Halle & Marantz, 1993). MEG results have suggested that early brain activity (M170) reflects pure sensorial processing of the phonological and/or orthographic forms, and later activity (M250 and M350) reflects the

lexical access and word identification (Fruchter & Marantz, 2015; Lewis, Solomyak, & Marantz, 2011; Stockall & Marantz, 2006). The SR share many principles with the Obligatory Decomposition (OB) proposed by Taft and Forster (1975).

On the other hand, Baayen, Milin, Đurđević, Hendrix, and Marelli (2011) proposed the amorphous Naïve Discriminative Learning (NDL) model based on a connectionist architecture with direct associations between form-to-meaning, it means, a direct activation from orthography to semantics (Devlin, Jamison, Matthews, & Gonnerman, 2004; Rumelhart & McClelland, 1986; Seidenberg, 2007). It is a probabilistic model which explores conditional behavior through the Rescorla-Wagner equation and linguistic entropy from the informational theory (Milin, Filipović Đurđević, & Moscoso del Prado Martín, 2009; Moscoso del Prado Martín et al., 2004; Rescorla & Wagner, 1972).

Between these extreme views in the word processing and recognition, dual-mechanisms models, such as the Augmented Addressed Morphology (AAM) (Caramazza et al., 1988; Domínguez et al., 2004), the Minimalist Morphology (MM) (Clahsen, 1999; Wunderlich, 1996), and the Words and Rules (W&R) and Declarative/Procedural (D/P) (Pinker & Ullman, 2002b), have proposed two routes for word recognition, a combinatorial rule-based route and an associative whole word activation route, in function of word regularity, frequency, and productivity.

Modern Romance languages like French, Catalan, Italian, Portuguese, Romanian, and Spanish evolved their vocabulary and grammar from Latin conserving its paradigmatic verbal inflectional system. On the left side of the verbal form is the stem (*v*) formed by the root ( $\sqrt{\text{v}}$ ) and the thematic vowel (Th), and on the right side is the tense node containing the temporal-mode tense suffix (T) and the personal-number agreement suffix (Agr) (i.e., [[[surf] $\sqrt{\text{v}}$ ][e]Th] $\sqrt{\text{v}}$ ][r]T[ons]Agr]T]TP *surferons* ‘we will surf’) (Arregi, 2000; M. I. Oltra-Massuet & Marantz, 1999).

Caramazza et al. (1988) investigated, using reaction times (RTs), the morphological processing of Italian inflected verbs using four types of pseudoverbs: a) morphologically illegal (MI) (e.g., *\*canzovi*), b) only base (e.g., *\*[cant]ovi*), c) only suffix (OS) (e.g., *\*canz[evi]*) and d) inexistent but morphologically legal (IML) (e.g., *\*[cant][evi]*). MI pseudoverbs were quickly rejected based on orthography consistency; OB and OS pseudoverbs, which present morphological structure but no functional or lexical morpheme, were processed with more difficulty, reflected in larger RTs than MI. IML pseudoverbs were processed with great difficulty and lead to even longer RTs, they present morphological

structure and existent morphemes, but illegal morphological combination. The authors proposed the AAM model, where known and high-frequency words are recognized by the whole word route and unknown and low-frequency words by morphological decomposition, accordingly to the RT prediction  $MI < OB = OS < IML$ .

In French, we recently investigated the morphological processing of verbs exploring RT and error rate differences through a behavioral experiment with different morphological structures in verbs and pseudoverbs (Estivalet and Meunier 2016b). We found that MI pseudoverbs are easily rejected, as a function of their orthographic idiosyncratic form, OB and OS pseudoverbs are differently processed, depending on the open list of lexical morphemes and the close list of functional morphemes for morphemic searching/activation. IML are slowly processed than existent morphologically legal (EML) words, probably due to the later inhibition processes in the recombination phase for word verification.

EEG and eye-tracking evidence showed that the processing of a word is reflected in its fixation time and brain event-related potentials (ERP). Words that are shorter, phonologically regular or frequent, and semantically or syntactically predictable from the context are fixated for a shorter time. Effects of word frequency and contextual constraint were found in the first negativity (N1) 50-150 ms after stimuli onset, signaling modulations in the visual activation, organization, and predictability (Serenó, 2003). “Another early marker of reading is the N250, which was originally found to be sensitive to orthographic similarity in combined masked priming and EEG studies. However, subsequent studies have shown that N250 is also modulated by lexical factors” (Carreiras, Armstrong, Perea, & Frost, 2014, p.93). It thus appears that early EEG modulations are only related to general visual and orthographic probability in the sensory system, preceding deeper and symbolic specific linguistic processing (Chen, Davis, Pulvermüller, & Hauk, 2013).

Aiming to investigate morphological decomposition, and morphemic activation, we applied an experiment inspired by Caramazza et al. (1988) with many improvements and local manipulations. Our experiment was in French language and we incorporated refinements for stimuli selection, control, and matching (Gustavo Lopez Estivalet & Meunier, 2016c); we also defined specific morphological structures and violations to be tested in a visual lexical decision task experiment coupled with EEG acquisition to track the time-course of lexical and functional morphemes processing (Pykkänen & Marantz, 2003). We tested the following verb types: a) MI (e.g., *\*barlond*), b) OB (e.g., *\*[parl]ond*), c) OS (e.g., *\*barl[ons]*), d) IML (e.g., *\*[parl][ins]*), and it was included e) EML words (e.g., *[[parl][ons]]* ‘we speak’). We

also tested verbs with a) one inflectional suffix (i.e., v+Agr: *parl[ons]*) or b) two inflectional suffixes (i.e., v+T+Agr: *parl[i][ons]*), and the same test was made on pseudoverbs (i.e., v+Agr: *\*barl[ons]*, v+T+Agr: *\*barl[i][ons]*).

These morphological manipulations were carefully suited to investigate and identify specific processes in the lexical and functional morphemes (Allen & Badecker, 2002; Ruth de Diego Balaguer et al., 2006), as also the precise phases in morphological processing during visual word recognition (Fruchter & Marantz, 2015; Schreuder & Baayen, 1995). Therefore, the questions that guided our study were: a) Which are the cognitive costs (reflected in RTs, error rate, and ERPs) in the processing of the different verbal morphemes? b) Which are the differences in the processing of forms containing lexical and/or functional morphemes? c) Which is the hierarchical morphological structure in the processing of French verbs?

We predict that MI pseudoverbs cannot be recognized by the whole word route or be decomposed because they have no meaning and no morphological structure, being rapidly rejected based on the idiosyncratic orthographic form. Then, OB pseudoverbs might present faster RTs and later EEG differences than OS; both verb types are similarly decomposed, but OS spends longer time searching for the base in a large and open list of lexical morphemes, while inflectional suffixes are highly frequent and organized in a close list of functional morphemes. In contrast, OS pseudoverbs will show slower RTs and early EEG violations than OB because while the stem is activated in the lexicon, the inflectional suffixes are not found and the pseudoverbs are quickly rejected. Also, we predict that EML words will be significantly slower than OB because there is a deep computation in the processing of the inflectional suffixes, but no significant different than OS, because the stem search/activation may be completed in a parallel processing. Further, IML pseudoverbs might present RTs slower than EML because in the late recombination phase there is inhibition and the form must be rejected based on the morphotactics, slowing RTs (Caramazza et al., 1988; Taft & Forster, 1975).

Afterwards, forms without inflectional suffixes should be recognized faster than forms with one inflectional suffix, and the latter might be recognized faster than forms with two inflectional suffixes because each affix involves a morphological operation and specific linguistic computation, requiring larger RTs for form processing and recognition (Gustavo Lopez Estivalet & Meunier, 2016b). Then, we predict to find later ERP effects reflecting the different structure violations in the recombination phase in the P600, especially regarding the IML pseudoverbs.

Our predictions are more in line with the OD model (Taft, 1979):  $MI < OB < OS = EML < IML$ , where morphemic search and inflectional computation should present different processes and additive effects in the time-course of word recognition. This predictions are different from single-mechanisms with whole word representations (Baayen et al., 2011; Devlin et al., 2004; D. E. Rumelhart & McClelland, 1986; Mark S. Seidenberg, 2007):  $EML < MI = OB = OS = IML$ .

In sum, we suggest that inflected (pseudo)verbs are pre-lexically decomposed in lexical and functional morphemes, then, they have their morphemic representations activated in the lexicon, which respectively activate their semantic and morphosyntactic features, and finally is recombined for word licensing and verification. The present study aimed to track morphological processing of words and the time-course of their decomposition, activation, and verification (Lavric et al., 2012; Pykkänen & Marantz, 2003; Rastle et al., 2000; Stockall et al., 2004; Taft, 1979) using French inflected verbs in a visual single-word lexical decision task coupled with EEG.

## 2 Method

### 2.1 Participants

Twenty participants adult native speakers of French between the ages of 18 and 38 years old ( $M = 21.5$  years old, 10 women) participated in the experiment. All participants were right-handed, had normal hearing, had normal or corrected vision, had no history of cognitive or neurological problems, and had at least 12 years of study (French BAC). Participants did not know the purposes of the experiment, they provided written consent, and were paid 20€ for their participation.

### 2.2 Materials and Design

Participants performed a visual lexical decision task. We tested five conditions of verb type based on morphological structures and violations: a) morphologically illegal (MI) (e.g., *\*barlond*), b) only base (OB) (e.g., *\*[parl]ond*), c) only suffix (OS) (e.g., *\*barl[ons]*), d) inexistent but morphologically legal (IML) (e.g., *\*[parl][ont]*), and e) existent and morphologically legal (EML) (e.g., *[[parl][ons]]* ‘we speak’). We also tested morphological

structures from a) the indicative present tense with one inflectional suffix (i.e., v+Agr: *parl[ons]* ‘we speak’) and b) the indicative imperfect past with two inflectional suffixes (v+T+Agr) (e.g., *parl[i][ons]* ‘we spoke’) in verbs and pseudoverbs (e.g., *\*barl[ons]*, *\*barl[i][ons]*). Examples of experimental conditions are shown in Table 1.

Verb Type	One Suffix (Agr)		Two Suffixes (T+Agr)	
1. MI	barlond		barl[i]ond	T
2. OB	[parl]ond	√	[parl][ai]ond	√+T
3. OS	barl[ons]	Agr	barl[i][ons]	T+Agr
4. IML	[parl][ins]	√+*Agr	[parl][ai][ons]	√+*T+Agr
5. EML	[[parl][ons]]	√+Agr	[[parl][i][ons]]	√+T+Agr

Table 1 - Examples of the different experimental conditions.

Three hundred French verbs from different lemmas were selected as experimental stimuli; then, the forms were carefully manipulated based on letter, bigram and trigram frequencies, and phonological distinction to accurately attend the specific criteria on each verb type investigated. From the 300 forms chosen and manipulated as experimental stimuli, 60 were words (EML) and 240 were pseudoverbs (MI, OB, OS, and IML). To counterbalance the word and pseudoword responses, we chose a set of 240 nouns. This distractor set was composed by 120 masculine nouns and 120 feminine nouns; in each noun subgroup, there were 60 singular forms and 60 plural forms in four different ending paradigms. Then, we created 60 nonwords using the *Lexique* toolbox (New et al., 2004), based on letter frequency, bigram frequency, and trigram frequency. The complete stimuli selection and creation process is explained in Appendix A.

For an objective control and match of the lexical characteristics of the experimental stimuli on pseudowords, we used the *Lexique* toolbox to calculate the letter, bigram and trigram frequencies, as also orthographic neighborhood in all experimental stimuli (New et al., 2004). Experimental stimuli is presented in Appendix B and matching lexical characteristics of word length, surface and lemma frequency, letter, bigram and trigram frequencies, and orthographic neighborhood are presented in Appendix C.



## 2.3 Procedure

The experiment was constructed and applied through E-Prime® 2.0 Professional (Psychology Software Tools, Inc., Sharpsburg, PA, USA ) (Schneider et al., 2012). First, a fixation point was displayed on the center of the screen for 1,000 ms; second, the target stimuli was displayed on the center of the screen for 2,000 ms or until the participant's response; third, an inter-stimuli blank screen was displayed with random onset asynchrony between 750-1,250 ms, and the presentation of a new stimulus started with the presentation of the fixation point. The stimuli were presented in the center of a computer screen 15" CRT with white letters against a black background in 18-point letter size and Courier New lowercase letters (.8°, width 1.5-4.3° visual angle). Participants were instructed not to blink their eyes during the presentation of the fixation point and target, but only after their responses; they were also oriented to relax, avoid jaw clench and muscular activity during the experiment to assure no artifact data contamination. Participants were tested individually in the *Laboratoire sur le Langage, le Cerveau et la Cognition (L2C2)*, Lyon, France, in a quiet EEG laboratory with dimly light; they were instructed to answer as quickly and accurately as possible using two keys from a computer keyboard where the right hand over the 'green' button corresponded to words and the left hand over the 'red' button corresponded to pseudowords. The measure of the RT began with the target screen onset and finished when the participants pressed a button.

Two lists were pseudo-randomly counter-balanced constructed using the Mix program (van Casteren & Davis, 2006), following the criteria: a) there were a maximum of three words or pseudowords repetition, b) there were no two consecutive targets from the same verb type or number of suffixes or class, c) there were no two consecutive targets beginning with the same letter, and d) there were at least five words between two targets with the same ending. The experiment started with an instructional screen, followed by 20 stimuli of practice; there were three blocks of 200 stimuli separated by two breaks of one minute each, totalizing 600 stimuli, and being performed in approximately 35 minutes.

## 2.4 EEG Acquisition and Statistical Analysis

EEG was recorded from 30 scalp positions including most standard 10/20 sites using active tin Ag/AgCl electrodes mounted in an elastic cap (actiCAP-32Ch, EASYCAP GmbH, Herrsching, Germany). Ground (AFz) and reference (FCz) electrodes from the cap were used

for data acquisition, and electrodes were further offline re-referenced to linked mastoids electrodes (TP9 and TP10). Two electrodes were used to record vertical (PO9) and horizontal (PO10) electrooculograms (EOG) for artifact rejection purpose. Signals were amplified using a BrainVision BrainAmp amplifier (Brain Products GmbH, Gilching, Germany) with of 1-70 Hz, half-amplitude-cutoffs, and recorded continuously with a digitization sampling rate of 1,000 Hz. Impedances were strictly kept below 5 K $\Omega$  in all scalp electrodes and below 10 K $\Omega$  in EOGs.

Data was cleaned deleting RTs between 300-1,800 ms (2.23%), and wrong responses (8.51%), accordingly to the behavioral results below. Artifact-free trials were initially automatically rejected using the EOG electrodes (3.89%); subsequently, individual trials were carefully visually inspected and rejected (1.98%), totalizing 15.52 % of the experimental stimuli excluded for EEG analysis using the FieldTrip toolbox (Donders Centre for Cognitive Neuroimaging, Nijmegen, Netherlands) (Oostenveld et al., 2011) on Matlab® software (MathWorks, Inc., Natick, MA, USA).

ERP data was 20 Hz low-pass filtered to improve readability, but all statistical analyses were computed on unfiltered data; baseline was computed by the mean amplitude relative to 100 ms pre-stimuli. Participant averages were calculated by condition from 100 ms before target onset to 900 ms after target onset, then, grand averages were computed across participants. Separate statistical analysis were performed in five time windows of interests defined on the basis of previous studies N1: 50-150 ms, P2: 150-250 ms, LAN: 250-400 ms, N400: 400-550 ms, and P600: 550-800 ms (Roehm et al., 2005). ERP effects were statistically evaluated independently for each time window of interest using a mixed-effects model with ERP grand averages as the dependent variable, participants as the random variable, and verb type, number of suffixes, left-right electrodes, and anterior-posterior electrodes (i.e., F3, C3, P3, Fz, Cz, Pz, F4, C4, P4) as fixed-effect variables.

## 2.5 Results

### 2.5.1 Behavioral RT and Error Rate

Only correct responses on experimental stimuli were analyzed; RTs faster than 300 ms and slower than 2,000 ms were considered out of task and discarded (2.23 %), and incorrect answers were removed for RT analysis (8.51 %), totalizing 10.56 % of the experimental data removed.

Three RT distributions were tested using one-sample Kolmogorov-Smirnov test: RT ( $D = .121, p < 2.2e-16$ );  $\log(\text{RT})$  ( $D = .068, p < 2.2e-16$ ); and  $1/\text{RT}$  ( $D = .035, p = 3.2e-7$ ), where the reverse transformation showed a more like-Gaussian distribution suitable for parametric statistical tests. The behavioral data were analyzed using two mixed-effects model (Baayen, 2008): one with normalized RTs (i.e.,  $1/\text{RT} * -1000$ ) as the dependent variable, participants and targets as random variables, and verb type (i.e., MI, OB, OS, IML, EML) and number of inflectional suffixes (i.e., one inflectional suffix vs. two inflectional suffixes) as fixed-effect variables; and another with the logit accuracy (ACC) as the dependent variable and binomial family specified in the model. The RT means, SDs, and error rates from the experimental conditions are shown in Table 2 and Figure 1.

Suffixes	One Suffix		Two Suffixes		Total	
Verb Type	RT(ms)	Error(%)	RT(ms)	Error(%)	RT(ms)	Error(%)
1. MI	721(244)	.10	815(313)	.15	768(284)	.25
2. OB	798(292)	.22	778(287)	.05	788(290)	.27
3. OS	870(306)	.90	917(327)	1.12	893(317)	2.02
4. IML	889(314)	1.53	972(338)	2.32	928(328)	3.85
5. EML	882(320)	1.75	919(308)	1.15	901(315)	2.90
Total	827(302)	4.50	873(322)	4.78	850(312)	9.28

Table 2 – RT means, SDs, and error rates from the experimental conditions by verb type and number of inflectional suffixes.

We then adjusted the model to better fit the general RT data by trimming residuals larger than 2.5 SDs (1.49%), i.e., standard model ( $R^2 = .57$ ), fitted model ( $R^2 = .62$ ) (Baayen, 2008), as shown in Figure 1C. The analysis of variance (ANOVA) of the RT mixed-effects model (Type III with Satterthwaite approximation for degrees of freedom) shows main significant effects of verb type ( $F(4,279) = 51.225, p < .001$ ), number of suffixes ( $F(1,280) = 17.569, p < .01$ ), as also a significant interaction between these two variables ( $F(4,279) = 4.102, p < .01$ ).

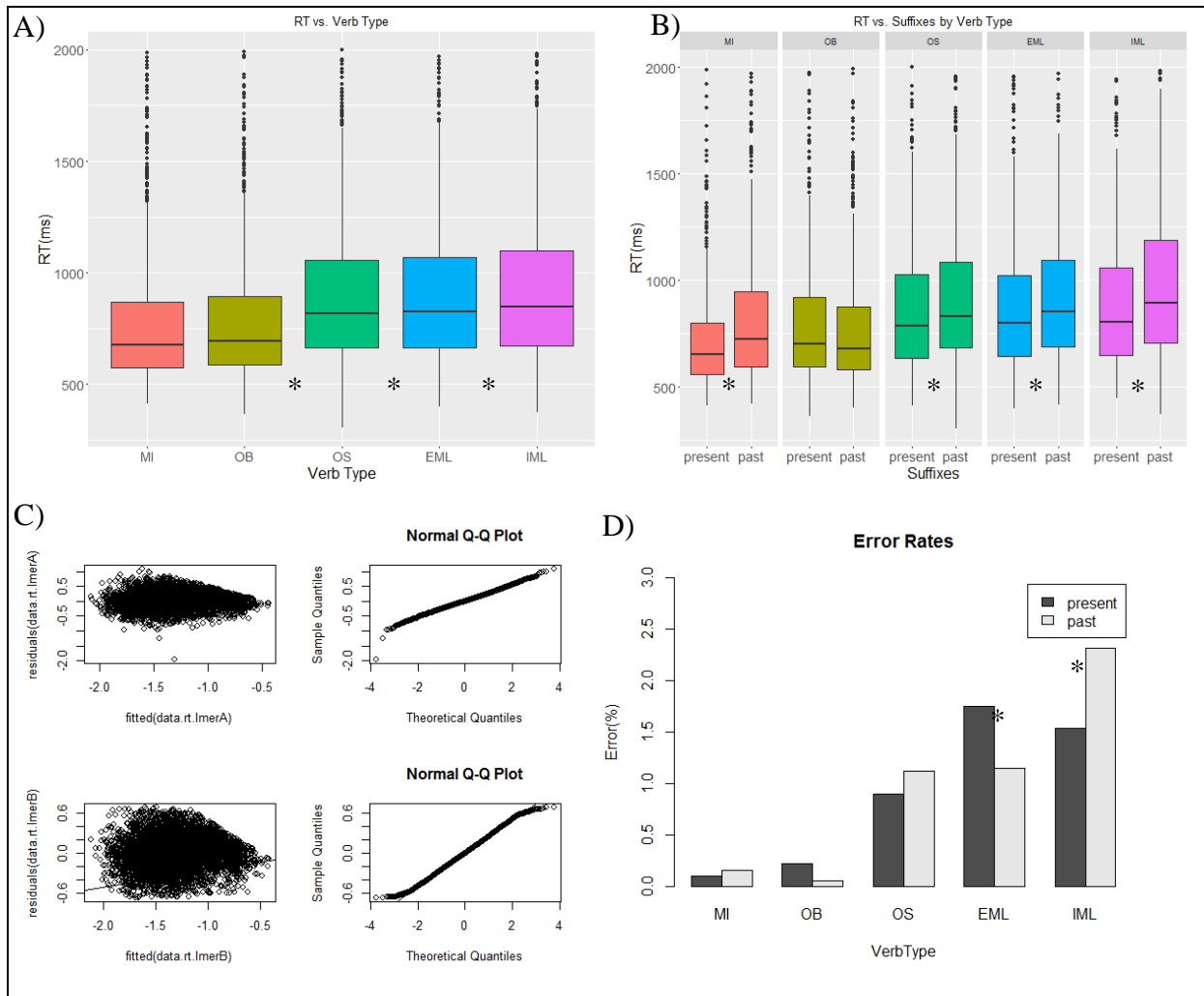


Figure 1 – A) RTs in function of verb types, B) RT in function of number of suffixes by verb type, C) Mixed-effect model fitting, and D) Error rates in function of number of suffixes by verb type.

Moving to the planned comparisons, we only report significant results. MI, OS, EML and IML present significant differences in the number of suffixes (respectively,  $t(264) = 4.198, p < .001$ ,  $t(282) = 2.777, p < .01$ ,  $t(288) = 2.486, p < .05$ ,  $t(299) = 3.063, p < .01$ ). We then analyzed the difference between the verb types tested. MI is significantly different from OS ( $t(278) = 9.068, p < .001$ ), EML ( $t(281) = 8.795, p < .001$ ), and IML ( $t(286) = 10.814, p < .001$ ). OB shows significant differences to OS ( $t(279) = 7.671, p < .001$ ), to EML ( $t(281) = 7.402, p < .001$ ), and to IML ( $t(287) = 9.425, p < .001$ ). OS shows significant difference to IML ( $t(295) = 2.294, p < .05$ ), and EML presents significant difference to IML ( $t(298) = 2.023, p < .05$ ).

Concerning the error rates, the analysis of deviance of the ACC mixed-effects model (Type II with Wald  $\chi^2$  tests) shows a main significant effect of verb type ( $\chi^2(4, N = 20) =$

220.731,  $p < .001$ ), but no differences in the number of suffixes ( $\chi^2(1, N = 20) = .848, p = .357$ ); there was also a significant interaction between verb type and number of suffixes ( $\chi^2(4, N = 20) = 27.512, p < .001$ ). In the planned comparisons, EML and IML show significant differences in the number of suffixes, (respectively,  $z = 2.316, p < .05$  and  $z = -3.467, p < .001$ ). MI presents significant differences to OS ( $z = -7.951, p < .001$ ), to EML ( $z = -9.628, p < .001$ ), and to IML ( $z = -11.006, p < .001$ ). OB shows significant differences to OS ( $z = -7.917, p < .001$ ), to EML ( $z = -9.643, p < .001$ ), to IML ( $z = -11.062, p < .001$ ). OS presents significant differences to EML ( $z = -3.315, p < .001$ ), and to IML ( $z = -6.326, p < .001$ ). EML shows significant differences to IML ( $z = -3.137, p < .01$ ).

## 2.5.2 Event-Related Potentials

ERP results from the target onset (0 ms) up to 900 ms from representative electrodes are shown in Figure 2. It can be noted small differences between the EML and pseudoverbs in the early time-windows N1 and P2, and more prominent patterns during the late time-windows LAN, N400, and P600. ANOVAs from the mixed-effect models in the different time-windows are shown in Table 3.

We then scrutinized the planned comparisons to identify the significant verb type differences and interactions in each time window (see Table 3). In the N1, MI is significantly different from EML ( $t(1411) = 2.961, p < .01$ ), IML ( $t(1411) = 4.128, p < .001$ ), and OB ( $t(1411) = 5.161, p < .001$ ); OS is significantly different from EML ( $t(1411) = 2.407, p < .05$ ), IML ( $t(1411) = 3.574, p < .001$ ), and OB ( $t(1411) = 4.607, p < .001$ ); then, EML is significantly different from OB ( $t(1411) = 2.201, p < .05$ ). In the P2, only MI is significantly different from EML ( $t(1411) = 2.394, p < .05$ ), IML ( $t(1411) = 2.807, p < .01$ ), OB ( $t(1411) = 2.237, p < .05$ ), and OS ( $t(1411) = 1.972, p < .05$ ).

In the LAN, MI is significantly different from EML ( $t(1411) = 5.832, p < .001$ ), IML ( $t(1411) = 4.747, p < .001$ ), OB ( $t(1411) = 5.267, p < .001$ ), and OS ( $t(1411) = -3.278, p < .01$ ); then OS is significantly different from EML ( $t(1411) = 2.555, p < .05$ ) and OB ( $t(1411) = 1.989, p < .05$ ). In the N400, EML is significantly different from OS ( $t(1411) = -2.976, p < .01$ ), IML ( $t(1411) = -2.736, p < .01$ ), and MI ( $t(1411) = -4.117, p < .001$ ); then OB is significantly different from IML ( $t(1411) = -2.877, p < .01$ ), OS ( $t(1411) = -3.116, p < .01$ ), and MI ( $t(1411) = -4.258, p < .001$ ). In the P600, MI is significantly different from EML ( $t(1411) = 3.901, p < .001$ ), IML ( $t(1411) = 2.624, p < .01$ ), and OB ( $t(1411) = 4.826, p < .001$ ); OS is significantly different from EML ( $t(1411) = 3.919, p < .001$ ), IML ( $t(1411) =$

2.643,  $p < .01$ ), and OB ( $t(1411) = 4.844, p < .001$ ); then OB is different from IML ( $t(1411) = -2.202, p < .05$ ).

	NumDF	DenDF	N1	P2	LAN	N400	P600
VerbType	4	1411	10.232***	2.451*	11.364***	7.403***	10.205***
Suffixes	1	1411	.176	.003	1.611	7.727**	.376
A-P	2	1411	.781	234.387***	47.674***	7.002***	12.893***
L-R	2	1411	2.571	8.955***	12.586***	.603	1.485
VT:S	4	1411	9.917***	8.787***	14.567***	7.477***	13.645***

\*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$

Table 3 – ANOVAs from the mixed-effects model in the different time-windows. VT: verb type, S: number of suffixes, A-P: anterior-posterior electrodes, and L-R: left-right electrodes.

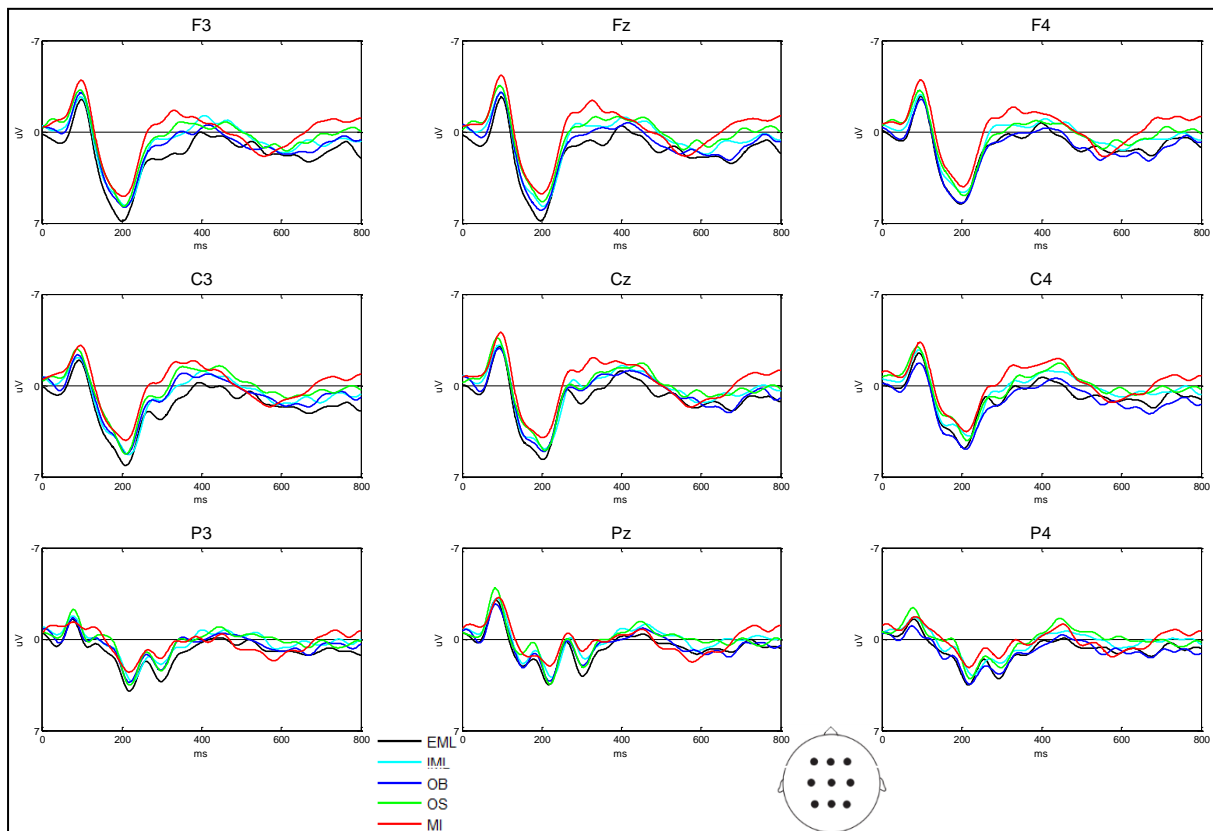


Figure 2 – Grand average from ERP (N = 20) at nine electrodes for the five experimental conditions. Negativity is plotted upwards.

Regarding the number of suffixes effect, there were significant differences in N1 only for EML ( $t(1411) = -5.202, p < .001$ ); in P2 for EML ( $t(1411) = -3.928, p < .001$ ), OB ( $t(1411) = -2.311, p < .05$ ), and OS ( $t(1411) = 2.662, p < .01$ ); in the LAN time-window, only for EML ( $t(1411) = -4.723, p < .001$ ) as in the N400 time-window EML ( $t(1411) = -5.495, p < .001$ ); and in the P600 time-window: EML ( $t(1411) = -5.348, p < .001$ ), IML ( $t(1411) = 1.976, p < .05$ ), and OS ( $t(1411) = 2.059, p < .05$ ). Finally, in what concerns the interactions, it becomes clear that it was provoked by the number of suffix effects in the EML verb type and the no effects in the MI. We were particularly interested in the differences between OB and OS verb types in the LAN/N400 time-window to verify possible difference in the time-course of the processing of the lexical and functional morphemes, as also between MI and IML verb types in the P600 time-window to verify differences in the recombination phase, thus we report only the significant interactions between these verb types and the number of inflectional suffixes. In the LAN there was only a significant interaction between OB and OS verb types ( $t(1411) = 2.291, p < .05$ ); in the N400 there were significant interactions between OB and OS verb types ( $t(1411) = 2.281, p < .05$ ) and between MI and IML verb types ( $t(1411) = -2.742, p < .01$ ); and in the P600 there was again only a significant interaction between OB and OS verb types ( $t(1411) = 2.418, p < .05$ ). ERP differences between the number of suffixes in the different verb type conditions are shown in Figure 3, the bottom right graph represent the control EML condition subtracted by the other verb type conditions.

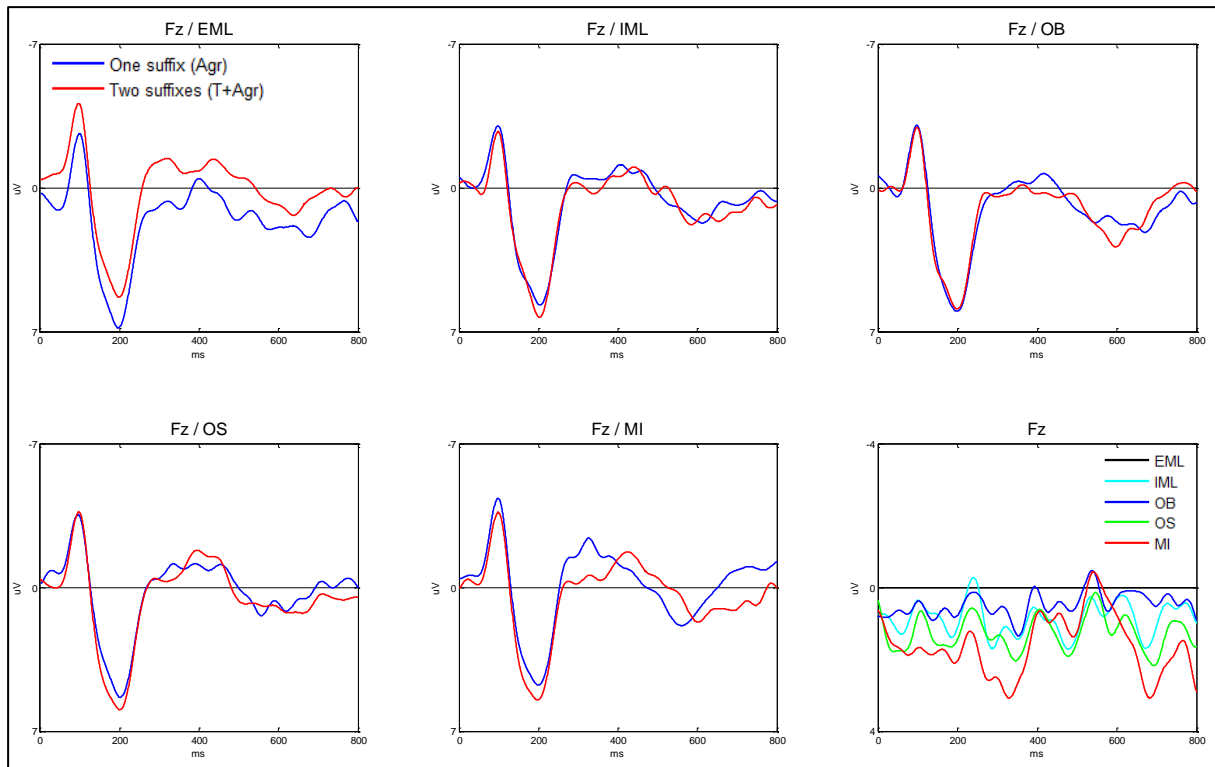


Figure 3 – Grand average from ERP (N = 20) at Fz electrode from the differences between the number of suffixes in the five experimental conditions. The bottom right graph represents the EML verb type subtracted by the other verb types. Negativity is plotted upwards.

The topographical distributions in the five experimental verb type conditions and five time-windows of interest show that the N1 present an occipital parietal bilateral activation consistent in the EML and OS verb types, and with right lateralized in the IML and MI conditions. The P2 is the most stable and invariable time-window, suggesting to be a general process which is not modulated neither by orthographic features, nor by linguistic factors. The LAN time-window present less activation in all conditions compared to the EML one. The N400 present a typical distribution in the EML condition, and different frontal activation in the other conditions (Lau et al., 2008). Finally, the P600 a typical positive activation in the left IFG in the EML condition and more central activations in the other condition, with a very weak positivity in the MI condition.

Finally, we verified the by-subject Pearson's product-moment correlations between the behavioral RTs and the ERP amplitudes in the different experimental conditions and time-windows of interest. These correlations were performed to investigate which ERPs directly influenced the RTs and which do not, and to understand which kind of specific violation in the verb types tested correlated more with the specific ERPs.



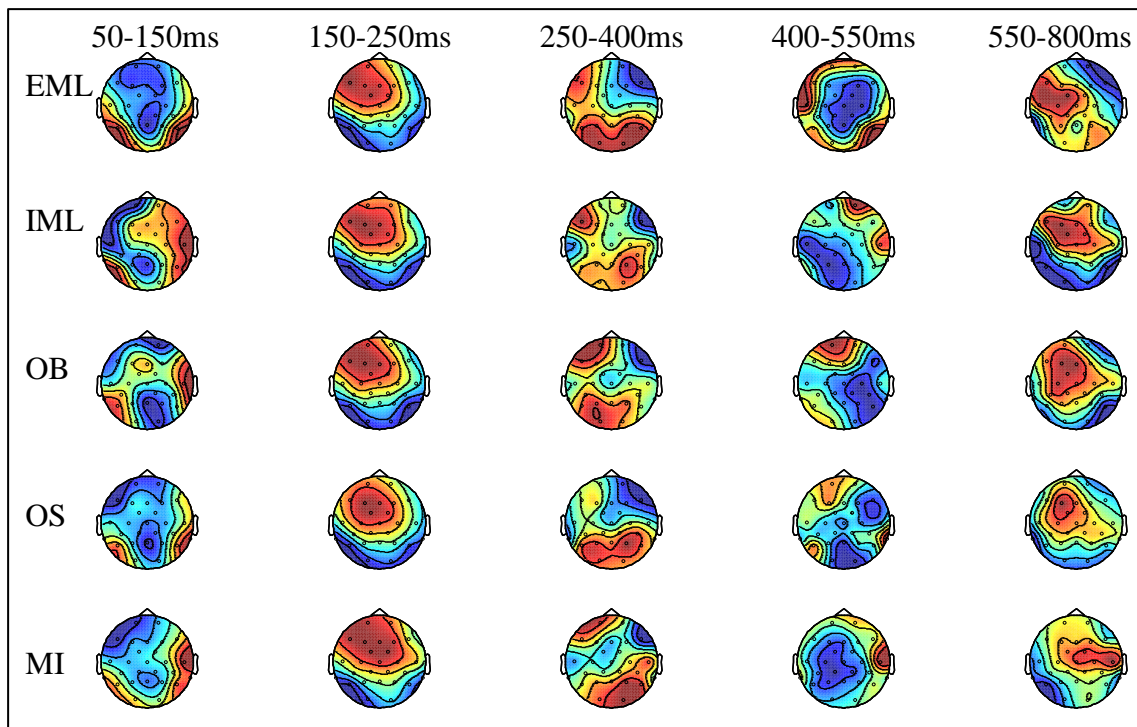


Figure 3 – Grand average topography from the different time-windows and experimental conditions.

VerbType/ERP	N1	P2	N400a	N400b	P600
EML	.251	.434*	.355*	.049	.227
IML	.053	.333	.097	-.077	.099
OB	.381*	.474**	.453**	.055	.415*
OS	.169	.423*	.258	-.259	.245
MI	.223	.486**	.239	-.148	.314
One suffix	.251*	.392***	.268*	-.074	.265*
Two suffixes	.179	.467***	.325**	-.023	.249*

\*  $p < .05$ , \*\*  $p < .01$ , \*\*\*  $p < .001$

Table 3 – By-participant Pearson's product-moment correlation from the normalized RT means and ERP amplitudes in the different experimental conditions and time-windows. Verb type DF(30) and number of suffixes DF(78).

### 3 Discussion

We investigated in this study the word recognition, morphological processing, hierarchical structures, and violations in French (pseudo)verbs through a lexical decision task in visual modality coupled with the EEG. We tested five verb types with different morphological structures (i.e., MI, OB, OS, IML, and EML), containing one or two inflectional suffixes. The results suggest that all French verbs are decomposed in French visual recognition (Gustavo Lopez Estivalet & Meunier, 2015a; Meunier & Marslen-Wilson, 2004). The main morphological units decomposed to verbal recognition are the lexical morpheme with the roots providing the semantic meaning, and the inflectional suffixes of tense and agreement, providing the morphosyntactic features.

This study showed that a) the number of inflectional suffixes, b) the inexistence of the base and/or suffixes, and d) the legality of the combination of morphemes in the formation of French verbs result in modulations and significant differences in word processing reflected in the behavioral responses and in different ERPs. Our results show that pseudoverbs which have only one existing morpheme, lexical morpheme (stem) or functional morpheme (inflectional suffixes), are decomposed for lexical access (Taft & Forster, 1975; Taft, 1991). It was observed that the presence of one or two inflectional suffixes influences RTs verbal morphological processing and late ERPs. The results in Table 2 and Figure 1 determine follow the hierarchy of RT responses according to verb types: \*MI = OB < \*OS < \*EML < \*IML, where the ‘less than’ represent significant differences between verb types and the ‘asterisk’ represent significant difference between the number of suffixes.

These results are different from the AAM (Caramazza et al., 1988) and WW (Baayen et al., 2011; Manelis & Tharp, 1977) predictions, however, they are in agreement with the OD predictions, where all words are morphologically decomposed, have their morphemes activated in the lexicon, and the morphemes are recombined and verified for word recognition (Taft & Forster, 1975; Taft, 1979). In sum, there was no significant difference between MI and OB, but significant differences between OB and OS, OS and EML, and EML and IML. MI, OS, EML, and IML verb types presented significant differences in the number of inflectional suffixes (Gustavo Lopez Estivalet & Meunier, 2016c).

MI are quickly rejected because they cannot be accessed by direct nor combinatorial route; unlike the AAM prediction, OB were not recognized significantly different from MI, but significantly different from OS. The orthographic stimulation immediately allows the

recognition or absence of inflectional suffix in the restricted and frequent list of functional morphemes, thus, OB pseudoverbs seems to be quickly rejected because the inflectional suffixes are not found in a frequent and close list of functional morphemes. In contrast, OS are significantly slower than OB because OS last longer for the stem search in the large and open list of lexical morphemes (Kenneth I Forster, 1992), as also the lexical morphemes have greater semantic complexity than the functional morphemes (Beard, 1995). OS pseudoverbs might also involve larger processing of the morphosyntactic representations and a trying to interpret the stem.

IML are decomposed and have their lexical and functional morphemes activated, however, when the morphemes are recombined, it cannot be verified as an existent word due to its illegal combination between morphemes. These forms enter in competition with other existing words which have the same morphemes, activating mechanisms of inhibition of lexical recognition and resulting in the longest RTs and highest error rates in the experiment (Caramazza et al., 1988). In the present study, we also tested EML verbs which were recognized significantly faster than OS and significantly slower than IML. Accordingly to the AAM, EML words should be recognized by the whole route, decreasing their RTs similar to MI or OB. Therefore, EML verbs IML pseudoverbs are decomposed, have their morphemic representations activated, both lexical and functional morphemes, and later, when the morphemes are recombined for word verification, only EML words are checked, while IML crash, resulting in faster RTs for EML words, and yielding their surface frequency.

The significant differences in RTs and rate error between one and two inflectional suffixes in EML and OS verb types suggests that all decomposable (pseudo)words are tried to be accessed by their atomic representations (Rastle & Davis, 2008; Taft, 1979). OS, EML, and IML verb types take longer to be processed and verified because there is more linguistic material and more features to be processed, slowing RTs and modulating ERPs. There is a clear distinction in RTs and error rates between verb types with lexical morpheme (OB, EML, IML) or without lexical morpheme (MI, OS), where forms with the stem yield more errors and longer latencies, as well as much larger SD. We verified possible difference in pseudoverbs created from French regular verbal forms from the 1st class and irregular verbal forms the 3rd class, but no significant difference was found.

Since the present experiment is a lexical decision task, it is natural to consider that the participants have a high expectative during the fixation point, which is resolved by the presentation of the target and the lexical decision. We note that in the ERP waves, this

expectative seems to be discharged in the first 250 ms, in the high amplitude and phase synchronized N1-P2 potentials elicited by the visual processing. It means that participants have large attentional resources in the onset of the presentation of the stimuli, which demands larger visual resources in this first 250 ms, and then the different conditions of verb type start to present graded differences, indicating the resolution of the expectative and the lexical access for word recognition. One could say that ERP modulations cannot be tracked in the first sensorial cycle, but the information is finely processed in the subsequent late and slower cycle, during lexical access. We note in the central and anterior electrodes the clear two cycles, one of .2 Hz between 50-250 ms, and another of .4-.55 Hz between 250 ms and 650-800 ms, with the later varying in the final of the cycle. Inversely, posterior electrodes have much more complex information of higher frequencies encoded in the first cycle until 350 ms, and then stabilize with no more large amplitudes until 800 ms.

Posterior regions are implicated in solving this early cycle and present resting information and/or feedback with minimal activation. Thus large expectancy is reflected in the first cycle and solved in the second by language executive control areas, which is reflected by the late differences after 550 ms in the anterior electrodes. Afterwards, the second cycle can be analyzed in two phases, and each phase observed in function of amplitude and latency.

Interestingly, the N1 mainly present differences between verb types that have the lexical morpheme or not, this result is probably associated with the lower orthographic probability of the MI and OS verb types which had the first letter of an existent stem changed to create a pseudo-stem. The P2 show differences only between MI and all other types, suggesting that at this point MI pseudoverbs have enough information to crash the lexical access and be rejected; we note that the MI are the only verb type tested which could be decomposed. The P2 is known as a potential which indicates a processing mechanism, probably here reflecting the trying of morphological decomposition (de Vega, Urrutia, & Dominguez, 2010).

In the LAN, again MI are different from all other verb types, but most important, OS are significantly different from OB and EML, indicating that the stem violation evokes a larger LAN than forms presenting an existent stem. Then, the N400 is known as reflecting the semantic integration and the word interpretation (Lau et al., 2008). Our results present differences again between OB and EML/OS verb types in the N400. It seems that only the P600 can disambiguate with significant differences between EML and OS. Interestingly, the N250 becomes clear only when we subtracted conditions (Morris & Stockall, 2012).

## 4 Conclusions

Overall, these results suggest a first cycle of visual sensorial processing until 250 ms after target onset and a second cycle with morphological processing and lexical access between 250-800 ms for word recognition. Our results shown that all decomposable (pseudo)words are parsed for lexical access, suggesting that a single-mechanism model with pre-lexical morphological decomposition can hold the French verbal inflectional system in visual modality (Gustavo Lopez Estivalet & Meunier, 2016c; Meunier & Marslen-Wilson, 2004). Verbal processing in in visual modality French is realized through an early and automatic decomposition between the stem and the inflectional suffixes, then, the morphemic representations are searched/activated in the mental lexicon in function of various lexical factors. In a phase, these lexical and functional morphemes are recombined and checked by the morphosyntactic representations as existent words, yielding their surface frequency (Marantz, 2013b; Taft & Forster, 1975; Taft, 1979). It is suggested that the word is first decomposed in stem and inflectional suffixes, then, the stem is first searched and activated, and the inflectional suffixes follows the same processes, the tense morpheme and the agreement morpheme.

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## Appendix A

Experimental stimuli were selected from a pre-filtered sub-corpus of 15,771 French verbs from the *Lexique* database (New et al., 2004). This sub-corpus contained verbs from the 1st and 3rd classes, indicative present and imperfect past tenses; it was pre-filtered by eliminating extreme lexical values, thus, keeping the verbs with 4-10 letters, .07-6,500 lemma frequency, .07-660 surface frequency, and 0-20 orthographic neighborhood. Three hundred French verbs from different lemmas were selected as experimental stimuli, this selection was automatically randomly performed 1,000 times from the pre-filtered sub-corpus, and we selected the set of 300 verbs which presented the lowest standard deviations (SD) on surface frequency, lemma frequency, word length, and orthographic neighborhood for word control and matching (Kenneth I Forster, 2000). The verbs were distributed in the five verb types investigated, being 60 by condition; the same random process above was performed to select the set of stimuli which presented the lowest SDs between verb types. In each verb type, 30 forms were inflected in the indicative present tense (i.e.,  $\sqrt{+Agr}$ ) and 30 forms in the indicative imperfect past (i.e.,  $\sqrt{+T+Agr}$ ). From this subgroup, 15 forms were regular verbs from the 1st class and 15 irregular verbs from the 3rd class, being three forms in each of the five inflectional agreements from the 1st and 3rd classes and indicative present and imperfect past tenses (i.e., i.  $[\emptyset]_{1c, pres, 1/3sg} \sim [-t]_{3sg}$ , ii.  $[-s]_{1/2sg}$ , iii.  $[-ons]_{1pl}$ , iv.  $[-ez]_{2pl}$ , v.  $[-ent]_{3pl}$ ). Then, the forms were carefully manipulated accordingly to Table 2 below based on letter, bigram and trigram frequencies, and phonological distinction to accurately attend the specific criteria on each verb type investigated.

To counterbalance the word and pseudoword responses, we chose a set of 240 nouns following the same automatic random process of selection described above (Kenneth I Forster, 2000). This distractor set had other investigation interests and was composed by 120 masculine nouns and 120 feminine nouns; in each noun subgroup, there were 60 singular forms and 60 plural forms in four different ending paradigms (i.e., *étudiant[e][s]* ‘student[f][p]’, *serv[eur/euse][s]* ‘waiter[m/f][p]’, *princip[al[e/s]][aux]* ‘principal[m[f][p]][mp]’, and *naï[f/ve][s]* ‘naïve[m/f][p]’). Finally, we created 60 nonwords using the *Lexique* toolbox (New et al., 2004), based on the following criteria: 20 nonwords created by letter frequency, 20 by bigram frequency, and 20 by trigram frequency; in each nonword subgroup, there were 10 nonwords with high frequency and 10 nonwords with low frequency. Letter: LF: 40K-80K, HF: 80K-120K; Bigram: LF: 2K-10K, HF: 10K-20K;

Trigram: LF: .2K-2K, HF: 2k-8K. Counterbalanced in word length: 4 letters: 6 nonwords, 5:6, 6:12, 7:12, 8:12, 9:6, 10:6.

Original	OB	IML	OS/MI
e	o	i	p ↔ b m ↔ n
(e)s	l	x	t ↔ d l ↔ r
t	n	e	k ↔ g a → e
ons	ond	ins	f ↔ v e → i
ez	em	is	s ↔ z i → a
ent	end	int	ʃ ↔ ʒ o → u

Appendix A – Manipulations performed on existent verbs to attend the experimental criteria on the verb types investigated. In forms with two inflectional suffixes were manipulated [-ai-] ↔ [-i-] in \*T.

## Appendix B

EML1	IML1	MI1	OB1	OS1
apercevons	abstraie	anterviend	adressond	blantes
appartenez	admettis	beignem	assaillend	brocédez
apportons	attirins	brétendn	cheminond	dendez
calment	claquint	briel	choil	ébordons
combattons	contemplis	cheignend	conduisem	éccrochez
complais	culotti	éban	créond	ésseyez
dément	débattins	foyagel	découvrem	éteignons
détaches	déliris	gonnaissem	défendem	garacole
dévalons	déserti	ichoin	détenond	gassez
élude	dorx	ixpirem	écorchem	gonclut
empiète	effleuri	lecullem	emmerdend	gonfondent
enduisent	endormint	léfugiond	entendond	graignons
ensuit	exagèret	lejoignond	entrevoil	groisons
entrouvre	imaginint	leliend	épouvanto	ipuisse
envoyez	inscrivint	leluisend	évoquel	itreignent
étendons	montret	lendond	expliquend	ledécouvre
félicitons	nommis	letitillo	houspillo	levends
fouaille	piailint	letrouvond	inclun	levoyez
imitent	piquins	lompl	justifiem	narques
parviens	prévenis	magem	maintiend	nédisent
permettent	prévoyins	téferlend	pourvoin	plottis
persistez	rabae	temandel	profitel	ponnit
remâchent	rassuret	ticto	rallongo	prasse



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renais	recourx	ubligo	reçoin	téduisons
répandez	repartins	ubtenond	réduisonnd	téshonores
ronges	ressere	voutem	ressenl	téversent
souciez	retenis	zèmend	retombel	veins
soustrait	revivint	zoufflond	soutiend	veutrent
surprenez	saurins	zouril	suggèrend	zédons
surveilles	survix	zuffil	sursautem	zubmergent

---

EML2	IML2	MI2	OB2	OS2
ajoutiez	accouris	aspiraiend	annotin	agnoriez
appreniez	bravit	attنديem	attachaiem	bartais
comprenez	brillis	bloquaiend	blâmil	bercevions
courbaient	concevaiez	bouffail	bouchil	chisions
cousaient	contenis	chantiond	bruissin	daissaient
couvrais	croyaiez	comptail	coincin	draduisais
débordais	désiraiez	convenail	crouliend	éccouchait
dépeignait	détrempit	cuvain	divorçaiond	émusions
dépendais	élançaiens	décrochail	ébattiend	fotaient
émettaient	émanit	défaisail	entravil	gignais
encastrait	foncis	détendiond	excluiend	gouriez
enfuyait	guindient	devenaiend	mentiend	guêtaient
enjoignait	moquaions	enquérain	mordin	icriviez
enleviez	mouraiens	fuyiond	naissaiond	ixerçaient
épousions	mouvit	gorgeain	nouiend	leposions
incitaient	pesaiens	habitiem	pendin	lévélait
joignaient	pondient	incrustain	pensaiem	levenaient
mimais	prédisit	jetiem	perdaiond	narrais
négligions	promettis	longeaiend	plaignil	pattait
offriez	puient	ouvraiend	rasseyil	prodais
paraissais	rampient	parcourain	redevenaiem	puvions
perçaient	refoutit	priviond	refaisaiond	raissiez
plaisions	regardaiez	rangiond	répondaiem	risaient
préfériens	remettaiez	reprenail	semblaiem	ruisait
proférait	rêvaiez	riaiend	sentaiem	tébarquiez

---

proposais	sortient	rouvrain	souffril	téplaisais
rappeliez	suivient	signiem	soumettin	tescendiez
retardait	supposis	teniem	terminaiond	tominions
servions	taisaions	valiond	tombiend	vaçonnait
souvenions	vendaions	viviem	tournaiond	zuspendait

---

## Appendix C

Verb Type	Word Length	Surface Frequency	Lemma Frequency	Letter Frequency	Bigram Frequency	Trigram Frequency	Neighborhood
EML	8,58	0,89	86,25	81551,60	12189,32	2837,58	1,80
IML	7,90	1,79	118,24	82776,68	12170,55	2291,98	1,63
MI	7,85	2,92	155,18	74488,30	7538,42	1061,68	0,85
OB	8,38	1,81	120,72	77747,95	8342,03	1332,90	1,20
OS	8,18	2,24	101,87	79623,88	11486,43	2487,75	2,05

Appendix C - Lexical characteristics matching.



## 4 General Discussion

In this main section, we present the general discussion from this thesis, including the theoretical background basis and the results from the five empirical studies about morphological processing in French verbs on visual modality. It is presented in section 4.1 the main present findings, 4.2 the stem frequency effects from Study 1, 4.3 the stem priming effects from Study 2, 4.4 the morphological operations effects in verbal inflection from Study 3, 4.5 the ERP time-course of verbal inflection from Study 5, 4.6 the morphological processing by bilinguals from Study 4, 4.7 the representations and processing within the mental lexicon, 4.8 the morphophonology of French verbal inflection, 4.9 the issues and alternatives from this thesis, and 4.10 the main limits, finding, and perspectives from the work developed here.

### 4.1 The Present Findings

“Language, that most human invention, can enable what, in principle, should not be possible. It can allow all of us, even the congenitally blind, to see with another person’s eyes” (Oliver Sacks, 1933-2015)

The theoretical background and empirical evidence presented above offer interesting insights in how the human cognitive system processes language, morphology, lexical access, and word recognition. In the present section, we put together the main findings from each experiment in a broader context of psychology, neurosciences, and linguistic research, and accommodate these results in a general to specific perspective of the morphological processing (Amenta & Crepaldi, 2012).

Our results are mainly in line with decompositional single-mechanism models since in all kind of French verbal forms: low and high surface frequency, low and high cumulative frequency, 1st and 3rd verbal classes, regular and irregular forms, theme vowel and allomorphic stem, one and two inflectional suffixes, lexical and functional morphemes, and word violations, there is no necessity to postulate a second route with whole word representations to explain the present results. The pattern of behavior in each experiment can

be explained by a combinatorial computational system which applies graded syntactic, morphological, and phonological processes for word formation in all French inflected verbs.

Also, our results suggest that the morphological decomposition is pre-lexical, words might be first decomposed, and then has their morphemic representations activated in the mental lexicon. The cumulative frequency effect strongly supports this interpretation because words with the same surface frequency are differently recognized in function of their cumulative frequency. The EEG experiment showed fine differences between words containing only stem or only inflectional suffixes, and suggests that the effects of the morphological processing precedes the whole word recognition. Nonwords were rejected faster than pseudowords, which means that morphological structured pseudowords engage decompositional processes before lexical access (Caramazza et al., 1988). Also, pseudowords containing only base or only suffix were rejected faster than real words, which suggests that words are not recognized by mean of their whole form and pre-lexical decompositional processes takes place for recognition (Estivalet & Meunier, 2016b). We suggest that the French verbal inflectional system is root-based, which means that all verbs follow combinatorial processes from atomic constituents.

## 4.2 Stem Frequency Effects

Study 1 showed significant differences between verbal forms with high and low surface frequency, but most important, the results showed significant differences between verbal forms with high and low cumulative frequency when the surface frequency was kept constant. This indicates that independently of the surface frequency, the stem frequency has an important role in word recognition, suggesting that words are decomposed to be recognized. While activation models use an activation system to generate candidates, search models provide the best alternative to explain the surface and cumulative frequency effects (Forster, 1992). Meunier and Segui (1999b) showed that French derived words with low and high surface frequency are cross-primed by morphological-related stems, suggesting that words are represented in their decomposed forms independently of their surface frequency.

In another masked priming experiment, Giraudo and Grainger (2001, p.438) “argue, however, that the learning process derives explicit representations corresponding to morphemes, and that these morphemes act as a partial interface between whole-word form representations and the representation of semantics”, but they conclude in favor of a supra-

lexical model for word recognition where whole forms are interactive-activated and then morphemic representations are activated by feedback propagation. The authors found priming effects in four experiments modulating surface and cumulative frequencies in morphology-related primes. Thus, this learning process cited by the authors, which results in morphemic representations, might be interpreted as the morphological acquisition based on the proceduralization of redundant forms and rules. Since the C-I system acquires a stable and productive rule for word formation, as it is the case for verbal inflection, there is no need to store all the forms which apply that rule, but the complex form is computed each time that its constituents are activated (Marantz, 2016).

Our results are in agreement with the Italian study which showed that the cumulative frequency, but also the surface frequency, determine RTs, playing different roles in the word recognition of inflected verbs (Burani et al., 1984). The authors concluded that words are represented in the mental lexicon by means of decomposed morphemes, but also that high-frequency and known words could be recognized by the whole word address system, based in the lack of differences between morphological and pseudo-morphological processing.

Moreover, later work showed that pseudo-morphological words are decomposed based on the pseudo-representation of stems and affixes, which means that words are decomposed based on an early and automatic process of their pseudo-morphological structure, disregarding semantics. It means that words which resemble to complex words are decomposed based on their apparent morphological structure (e.g., *baguette/bague* ‘stick/ring’), supporting the hypothesis that words are represented by means of their constituents in the mental lexicon, and not as whole words (Longtin & Meunier, 2005; Longtin et al., 2003; Rastle et al., 2004). Therefore, if even pseudo-morphological words are early automatically decomposed for a tentative of morphological, it seems safe to argue that real complex morphological words, especially inflected verbs underlined by a systematic and frequent set of stems and inflectional suffixes, are decomposed for lexical access. These results seem to extinguish the role of the whole word route, attributing a stronger role for the combinatorial one.

Concerning the interpretation of the frequency effect, Monsell et al. (1989) compared the frequency effects of lexical decision RTs in four tasks for the same words and participants, they found: a) no effects for semantic categorization (i.e., person vs. thing), b) significant effects for syntactic categorization (i.e., noun vs. adjective), c) significant effects for stress final words in a naming task, and d) significant effects in delayed naming. These findings undermine the post-lexical processing and favors the idea that the frequency



effects is the major locus for lexical identification in the late retrieving of the meaning and phonological form, as shown in Figure 28.

Figure 28 - The processing architecture supposed to underlie performance of categorization, lexical decision, and naming tasks (Monsell et al., 1989).

Meaning, syntactic, and phonological activation are realized after lexical identification. It seems that at the stage of lexical access, the stimulus is only encoded at a sensorial level, it means, the phonetic features organized in a phonological envelope and the orthographic features encoded in an image; but it has not yet any semantic, syntactic, and phonological representation. Thus, this is not yet a word; pseudowords and nonwords present exactly the same processes until 200 ms and basic sensorial phonological processing in the STG (Bouchard et al., 2013; Friederici, 2002) and orthographic processing in the occipital lobe and VWFA (Dehaene & Cohen, 2011; Lewis, Solomyak, & Marantz, 2011). For the activation of semantics, syntax, and phonology, the word form has to be decomposed to compute these morphological information (i.e., stem: semantics, suffixes: morphosyntax, and word: phonetic form), and if all these information together do not crash, it can be recognized as a word.

Cole et al. (1989) investigated the influence of surface and cumulative frequencies in derived French words with prefixes and suffixes. They showed that cumulative frequencies determine the latencies of suffixed words, but not prefixed ones, and that suffixed words from the same morphological family vary in function of the surface frequency, as is expected in decompositional models. Later, Colé et al. (1997) refined the model in three experiments with differences of surface and cumulative frequencies between primes and targets, suggesting that the mental lexicon might be composed of independent representations of words and

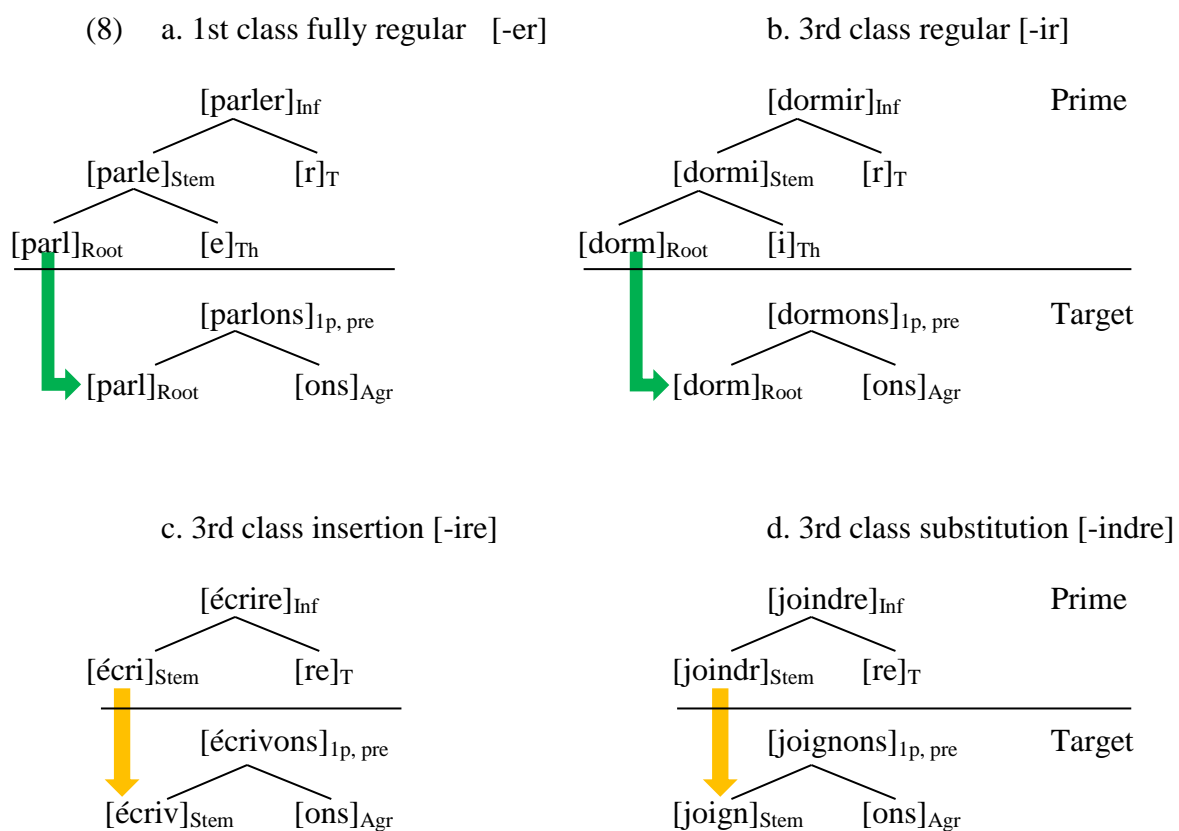
morphemes used by other members of the morphological family. The family size effect is related to the port-lexical semantic processing which naturally activates other morphology-related family members in the mental lexicon (Amenta & Crepaldi, 2012; Pylkkänen, Feintuch, Hopkins, & Marantz, 2004). The authors proposed a model which considers the letter level, morphological level, word level, and conceptual level, being in line with the TL model presented by Allen and Badecker (2002), as shown in Figure 29. However, we argue that instead of a direct activation from the letter level to the word level, the word form has to be mediated by the morphological level.

Figure 29 – Word processing network incorporating separate letter, morphological, word, and conceptual levels (Colé et al., 1997).

EEG research has showed that surface frequency effects takes place in the latter phase of the N400 (Kutas & Federmeier, 2000; Lau et al., 2008), which is suggested to be the semantic access in a later phase of the word recognition. Embick et al. (2001) showed MEG evidence that the frequency effects significantly modulate only the M350 component, confirming that frequency effects takes place later during the word recognition, only after the basic sensorial processing and early morphological processing of word constituents, as can be seen in Figure 14.

### 4.3 Stem Priming Effects

Study 2 found similar results in the both experiments applied, cross-modal priming and masked priming. We found full priming in the 1st class fully regular verbs in [-er] and 3rd regular verbs in [-ir], as shown in (8a,b); and partial priming in the 3rd allomorphic insertion verbs in [-ire] and 3rd class allomorphic substitution in [-indre], as shown in (8c,d). These priming effects were obtained by a stem-related prime compared to identity and unrelated control primes.



In the [-er] and [-ir] verb types, the prime and target are completely decomposed in stem and inflectional suffix, and the stem in root and theme vowel, if available, resulting in a priming of the same root between prime and target (Clahsen, 1999; Veríssimo & Clahsen, 2009). Even if the French verbal system is not classified in terms of theme vowels because they were erased in many forms and reinterpreted as a root vowel or agreement suffix, it seems that theme vowels still making part of the morphological processes for verbal inflection (Foley, 1979).

Similarly, in the [-ire] and [-indre] verb types, the prime and target are completely decomposed in stem and inflectional suffix, however, the stem cannot be anymore decomposed, thus, it follows that prime and target stems are not exactly the same forms, yielding the partial priming. An interesting question is: Are these allomorphic stems separately represented in the mental lexicon (e.g., [écri-]<sub>C</sub>~[écriv]<sub>V</sub>; [joind-]<sub>C</sub>~[joign-]<sub>V</sub>), where the former stems are combined with consonantal inflectional suffixes, and the latter stems are combined with vocalic inflectional suffixes? Or are there morphological allomorphic rules which transform one underlined abstract representation in another allomorphic stem accordingly to the morphological context (i.e., [√ire] → [√iv|√is]/\_V; [√indre] → [√ign]/\_V)? It seems that other experiments will have to be applied to clear cut between these two possibilities.

Our results are in line with priming experiments which shows that cross-modal task allows a core activation of the morphological representations in the mental lexicon through different modalities, accounting for large facilitations in the morphology-related primes, comparable to the identity primes, and significantly different when compared to control primes (Allen & Badecker, 2002). Meunier and Segui (2002) showed that in French, differently from English (Marslen-Wilson et al., 1994), two derived words from the same family stem prime each other, suggesting that derived words in French can be decomposed based on the semantic and formal transparency, and the morphological structure. We replicated our findings in the masked priming experiment which is not sensible to semantic relations or orthographic overlap between prime and target (Forster & Davis, 1984; Forster, 1998). Our results are therefore in line with models which propose early and automatic morphological decomposition based on the orthographic form (Lavric et al., 2007; Rastle et al., 2000, 2004; Rastle & Davis, 2008; Taft, 1979, 1991).

Crepaldi et al. (2010) propose that the masked priming task might have a second level of morphological priming in the lemma level, where inflected words, but not derived, share their morphological representations irrespective of regularity in a higher level. This position is in accordance to the TL model of Allen and Badecker (2002), where words have decomposed representations in the lexeme level which subsequently activate their respective lemmas in a higher and more abstract level, accordingly to Figure 21. Our partial priming results in the 3rd class allomorphic verbs in [-ire] and [-indre] support the interpretation that independently of formal differences in the lexeme level between prime and target, the prime is decomposed and activates the lemma level; thus, when the target is presented there is a facilitation in

comparison to the control condition, but not in the same level of the formal facilitation yielded by the lexeme level in the identity condition, resulting in the partial priming.

In an EEG study on French verbs, semantic, orthographic, and morphology-related masked primings yielded different patterns of ERP when compared to unrelated controls. There was no semantic priming, but significant orthographic and morphological priming effects with different patterns. The authors argued that “these results are consistent with models of lexical processing that make reference to morphological structure” (Royle, Drury, Bourguignon, & Steinhauer, 2012, p.3542). While in the early time-window between 175-450 ms there were orthographic and morphological priming, in the later time-window 450-550 ms there was only morphological priming effects, as shown in Figure 30. These results confirm that only morphological effects hold in the later N400 time window (Morris & Stockall, 2012).

Semantic effects could not be observed in this experiment probably because they reflect complex post-lexical activations of words semantically related (Lavric et al., 2007). The orthographic effects held only in the early time-window based in the phonological/orthographic processing of the forms (Domínguez et al., 2004). The morphological effects held in the later time-window based in the facilitation of the morphology-related priming during the stem search and activation. Another simpler interpretation is that this significant effect only in the morphological condition reflects the facilitation between the recombined whole forms in the prime and target based in the post-lexical family size effect which activates morphological related words (Fruchter & Marantz, 2015; Pykkänen et al., 2004).

Zipse, Kearns, and Marantz (2006, p.208) found identity priming facilitation only in the MEG M350, “the M350 has been hypothesized to reflect spreading activation among lexical entries, and it has been shown to be attenuated by identity priming”, which are in line with the frequency and priming effects in the EEG N400 (Lau et al., 2008). Thus, the family size effect might be a complex processes of spreading activation to semantic and phonological/orthographic related forms (Caramazza, 1997). Anyway, we remark that the family size in Romance inflected verbs may be very close between all verbal forms because almost all verbs have the same number of conjugations. Thus, all forms already have a high family size, let’s say 48 accordingly to Figure 23, plus more some variations in the nouns, adjectives, and adverbs formed with the same root.

Figure 30 – Significant differences between 175-450 ms and between 450-550 ms in the morphological priming condition (Royle et al., 2012).

These results are in line with an early sensorial processing of the input stimuli and a later lexical access of the properties of the stem and functional access of the affixes features in the words. Another masked priming MEG study comparing morphological to control primes in identity, regular, irregular, and pseudo-irregular English words found that late M350/N400 priming effects in the middle temporal ROI are significant for identity, regular, and irregular words, but not for pseudo-irregular ones. It was expected a significant difference also in the pseudo-irregular condition because many studies has shown that morphological decomposition also hold in masked priming for words that present pseudo-morphemes (Crepaldi et al., 2010; Longtin & Meunier, 2005; Longtin et al., 2003; Rastle et al., 2004). One possibility is that the pseudo-irregular behavioral priming is only driven by an early sensorial visual decomposition which does not have any consequence in the late lexical access and word processing, alternatively, the source of this process may be localized outside of left temporal cortex, as shown in Figure 31.

Figure 31 - Mean activity in the middle temporal ROI by prime type and experimental condition: A) Identity (car-CAR), B) Regular (jumped-JUMP), C) Irregular (fell-FALL), and D) Pseudo-irregular (bell-BALL). Significant M350/N400 priming effects are shaded in gray; other time windows were not tested for significance (Fruchter et al., 2013).

We note that the similar experimental protocols with cross-modal or masked priming experiments with control, identity, and morphology-related priming were already explored in other languages, such as English (Allen & Badecker, 2002; Crepaldi et al., 2010; Morris & Stockall, 2012; Münte et al., 1999), German (Clahsen, 1999; Penke et al., 1997; Weyerts et al., 1996), Catalan (Rodriguez-Fornells et al., 2001), French (Meunier & Marslen-Wilson, 2004; Meunier & Segui, 2002; Royle et al., 2012), Italian (Gross, Say, Kleingers, Clahsen, & Münte, 1998; Orsolini & Marslen-Wilson, 1997; Say & Clahsen, 2002), Portuguese (Veríssimo & Clahsen, 2009), and Spanish (Domínguez et al., 2000, 2004). In general, results on verbal inflection from Germanic languages has supported dual-mechanism models where regular words are recognized by the rule-based route and irregular words by the whole word route, and results from Romance languages has suggested that only the 1st class is driven by root-based computations while the 2nd and 3rd classes are whole word or sub-lexically stored

(but see Arregi, 2000; Bassani & Lunguinho, 2011; Oltra-Massuet & Marantz, 1999; Orsolini & Marslen-Wilson, 1997; Stockall & Marantz, 2006).

Two points may be remarked. First, inflected verbs from Romance languages almost always present forms with bound stems and inflectional suffixes while Germanic languages present free stems and allomorphic forms without affixation. It means that Romance languages always demand the processing of the lexical morpheme and also the functional morphemes which are combined to the bound stems to form a word, independently of the stem regularity (e.g., French: *je joue/je jouai, je prends/je pris*; Italian: *io giocai/io giocavo, io prendo/io presi*; Spanish: *yo juego/yo jugué, yo cojo/yo cogí*; Gloss: ‘I play/I played, I take/I took’). In contrast, Germanic languages demand the processing of the lexical morpheme and functional morpheme combined with the free stem in regular verbs, but only the processing of the lexical morpheme in irregular allomorphic free stems (e.g., English: ‘I play/I played, I take/I took’; German: *Ich spiele/Ich spielte, Ich nehme/Ich nahm*; Dutch: *Ik speel/Ik speelde, Ik neem/Ik nam*).

Second, within Romance languages, French results presented different results from other languages. French has shown no differences in word processing and recognition between the different types of verbs from the different verbal classes (Bonami et al., 2008; Estivalet & Meunier, 2016; Meunier & Marslen-Wilson, 2004). It seems that all French inflected verbs, fully regular verbs from the 1st and 2nd classes and irregular verbs from the different 3rd micro-classes, can be processed by a single-mechanism with morphological decomposition. French verbs from the 3rd class do not have to be stored as whole words or sub-structured stems because they follow the same inflectional processes than fully regular verbs regarding the functional morphemes, but have only an additional processing of the lexical morphemes which present allomorphic stems. In this sense, a large part of this allomorphic processes are predictable by the language morphological and phonological constraints, establishing productive allomorphic rules (Marantz, 2013a; Marslen-Wilson & Zhou, 1999; Oltra-Massuet, 2013). Thus, since these predictable productive allomorphic rules are acquired, they might be applied without restriction, such as simple morphographic rules from the 1st class *mangeons* ‘we eat’ and *plaçons* ‘we place’.



## 4.4 Inflectional Effects

Study 3 showed that French inflected verbs present significant differences in RTs and error rates between verbal forms with one inflectional suffix and two inflectional suffixes. Experiment 1 showed that independently of the tenses and agreements compared, verbal forms with these inflectional suffixes present longer RTs than verbal forms with only the agreement suffix (i.e., *jouent* < *jouaient* ‘they play < they played’). These results suggest that each morphological operation has a specific cognitive cost to be performed, being an additional effect to the frequency effects. Importantly, we found these effects in regular verbs from the 1st class and irregular verbs from the 3rd class, suggesting again that independently of their regularity, all French verbs are decomposed for morphological processing and word recognition. Even more, we found this effect in inflected verbs with high and low surface frequencies, suggesting that the processing of different inflectional suffixes take place in high and low surface frequencies. There was no significant interaction between these three factors, showing that these effects are independent. Thus, a single-mechanism model with morphological decomposition hold for our results in high and low surface frequencies, and regular verbs from the 1st class and irregular verbs from the 3rd class.

The significant difference between French verbal forms with one and two inflectional suffixes in high surface frequency words, as also the significant differences between verbal forms with high and low cumulative frequencies in high surface frequency words, seems to rule out the hypothesis that words with high frequency are stored and accessed as whole units in the mental lexicon (Booij, 2010b; Bybee, 1995; Caramazza et al., 1988; Ford, Marslen-Wilson, & Davis, 2003).

Experiment 2 narrowed the conditions between forms from the indicative present and imperfect past tenses, and between 1st plural and 2nd plural agreements (e.g., *jouons/jouez/jouions/jouiez* ‘we/you<sub>pl</sub> play/played’). We found significant differences between tenses in both agreements, but only an agreement difference in the indicative imperfect past tense. Our results support the morphosyntactic features underspecification hypothesis (Noyer, 2006; Penke et al., 2004), where morphemes do not have to be fully specified in their morphosyntactic features, but might present only those features which are important for the word processing. Therefore, the interpretation of the [past] feature activated by the [-i-] indicative imperfect past functional morpheme yielded significant differences from the present tense with zero tense morpheme (Clahsen & Ali, 2009). For the 2nd plural agreement, the [2nd] person feature is underspecified because it is the default morpheme from the plural

agreement, resulting in faster RTs than the fully specified [1st, plural] morpheme (i.e., [-ons]<sub>1st, plural</sub>, [-ez]<sub>plural</sub>).

From our knowledge, it was the first time that experiments of this type were applied. The picture is that word recognition is more than a simple match between an arbitrary abstract phonological/orthographic form and a possible meaning of this form. Word recognition is even more than lexical access, it is lexical access and functional access and other operations to anchor the phonological and syntactic information from a semantic meaningful form driven by specific language constraints (Marantz, 2016).

Frenck-Mestre et al. (2008) showed that violations between the subject-verb agreement phonologically realized (e.g., \*<je *parles*> ↔ /ʒə'paRl/) yield larger P600 than phonologically silent violations during a reading task (e.g., \*<je *parlez*> ↔ /,ʒəpaR'le/). These results support the hypothesis that the orthographic form is obligatory converted in the phonological form during silent reading. They did not find any earlier effect, suggesting that the P600 indexes processes of verification, in this case, the verbal agreement features checking accordingly to the sentence subject (den Dikken, 2011). Thus, beside the orthographic violations in both conditions, the phonologically realized agreement condition present significantly larger P600 than the phonologically because it is not homophone to the correct inflection (e.g., <je *parle*> ↔ /ʒə'paRl/) (Carrasco-Ortiz & Frenck-Mestre, 2014). We note that in our Experiment 2, both agreement forms chosen present phonologically realized agreement (e.g., *parlons-parlez* /paR'lɔ̃/-/paR'le/ 'we speak-you<sub>pl</sub> speak'), but only the 2nd plural form present homophones with the infinitive and past participle forms (i.e., *parler-parlé* /paR'le/ 'to speak/spoken'), which also explain why 2nd plural forms were recognized faster than 1st plural ones.

These results are in agreement with TL models, words from sensorial stimuli activate phonological/orthographic formal representations in the lexeme level, then, this forms can be decomposed and the morphemic representations activate the abstract lemma level with the conceptual meaning, while inflectional suffixes activates in parallel the morphosyntactic features (Allen & Badecker, 1999, 2002; Caramazza, 1997). Thus, the tense morpheme demands more phonological/orthographic processing, and also, a morphological node and morphosyntactic features to be interpreted.

## 4.5 Inflectional Time-Course

Study 5 investigated different types of (pseudo)verbs with one or two inflectional suffixes. The behavioral results showed no difference between forms morphologically inexistent (MI, *\*barlond*) and forms containing only base (OB, *\*parlond*), but significant differences between OB and forms containing only suffixes (OS, *\*barlons*), significant differences between OS and existent morphological legal forms (EML, *parlons* ‘we speak’), and significant differences between EML and inexistent morphological legal forms (IML, *\*parlont*) (Estivalet & Meunier, 2016c). MI are quickly rejected because they cannot be decomposed or be found as a whole word from their idiosyncratic form. OB and OS are decomposed based on their base and inflectional suffixes, respectively (Caramazza et al., 1988). Importantly, while OB are quicker rejected because their pseudo inflectional suffixes are not found in a short, closed, and frequent list of functional morphemes, OS take longer because they spent time searching for the pseudo stem in a large and open list of lexical morphemes, slowing RTs (Forster, 1992; Murray & Forster, 2004). EML are decomposed, have their lexical and functional morphemes activated, and then are recombined for word verification and licensing, presenting longer RTs. Finally, IML have these same stages of morphological processing, but the later phase crashes, resulting in inhibitory processes and slower RTs, as summarized:  $MI = OB < OS < EML < IML$ .

These results seems to clarify the pre-lexical morphological decompositional hypothesis, if words were recognized by their whole forms and then had their morphemes activated, all pseudowords should present the same long RTs because they were searched in the mental lexicon and not found because they have no surface frequency, and EML should present faster RTs because they obligatory has a higher surface frequencies, as  $EML < MI = OB = OS = IML$ . In the same line, dual-mechanism models would predict faster whole word access in EML words. Importantly, we found significant differences between OB and OS, and between EML and IML. The former results suggest an early difference in the morphological time-course processing between the lexical and functional morphemes and the latter suggest a later process in the time-course for the word verification and licensing.

As expected, we also found significant differences between forms with one or two inflectional suffixes in the OS and EML verb types; IML inhibitory processes for rejection seems to blurry these effects because of the larger variance, as also large error rates. Interestingly, we found this effect in the OS verb type, which means that independently of an

inexistent stem which crashes in the search, differences in the inflectional suffixes were tracked.

In the ERP analyses, there were small significant differences in the early N1-P2 ERP time-windows and more gradient differences in the LAN, N400, and P600 time-windows. Our results suggest stem modulation in the LAN and modulations from the inflectional suffixes in the subsequent N400. This is in line with the OD and SR model which proposes an obligatory morphological decomposition for word recognition. Lewis et al., (2011) found MEG results that the M170, which is probably an equivalent of the ERP P2, is modulated only by orthographic factors and do not make contact with the mental lexicon, where strings are associated to semantic representations.

Our results are in the same line, from onset to 250 ms there is very small modulations, these early differences are more prominent between EML and MI verb types, which can be explained by French phonotactics/orthotactics. Thus the lasted negativity between 250-550 ms can be divided in two phases LAN and N400, where the former present larger amplitude in OS, and the latter in OB, when compared to EML words. It means that pseudoverbs without stem provoked larger LAN and pseudowords without inflectional suffixes larger N400. Our results are in line with de Diego Balaguer et al. (2006) that there are different neurocognitive processing of the lexical and functional morphemes. The authors' results suggest that Romance inflected verbs might present grammatical processing of the functional inflectional suffixes in Broca's area and lexical stem activation of semantic properties in the left temporal lobe.

The general mean of correct responses in our experiment was 880 ms, interestingly, it is followed by a zero ERP at 900 ms, which seems to indicate attention and memory reset. We would like to propose that the recombination phase is represented by the P600, as it is known to be yielded by a process of verification and reparations. The P600 presented larger differences between EML and IML words, suggesting a violation in the recombination phase, however, evidence has been showed that the M350/N400 already indicate the word recognition. Anywhere, these results come from English experiments which yield faster RTs, around 550 ms, than Romance language experiments, probably because inflected English words are shorter and have less morphological complexity than words in Romance languages. As introduced above, the P600 seems to index sentence verification and reparation, thus, in sentence studies with subject-verb violations (Carrasco-Ortiz & Frenck-Mestre, 2014; Frenck-Mestre et al., 2008), the P600 can be interpreted as the verbal agreement features checking

with the subject of the sentence, but what exactly reflect the P600 and single word lexical decision experiments? The hypothesis that the P600 indexes the verification and licensing of the recombination phase between morphemes remains to be verified.

## 4.6 Bilingual Effects

Study 4 showed differences between beginner and advanced speakers of French as L2 in the frequency effects experiment, suggesting differences in the organization of the mental lexicon accordingly to proficiency in function of the French frequency norms. However, they do not show differences in the experiment with different morphological structures, suggesting that both beginner and advanced speakers apply the same processes for word recognition in French as L2. Accordingly to the D/P model for second language acquisition, words are first learnt and stored in the declarative memory and later after the accumulation redundant representations, words become to be processed by the procedural memory following grammatical rules (Ullman, 2001c). Thus, there seems to have a fast shift from the declarative to the procedural memory, because beginner and advanced speakers did not present differences in the processing of verbal morphological structures.

In the frequency effect experiments, our results indicate that while beginner bilinguals are not sensible to the frequency norms, presenting results with no tendency for surface effects, advanced bilinguals present surface frequency effects and have a mental lexicon organization towards the frequency norms (Lehtonen & Laine, 2003). Nevertheless, even advanced bilinguals present a behavior different from native speakers, which present strong significant surface and cumulative frequency effects in the verb types tested. These results support the idea that larger proficiency, as defined by the time of L2 exposition, determines the organization of the mental lexicon accordingly to the frequency norms (Dijkstra, 2007).

Importantly, beginner speakers had in mean 2.8 years of French contact, and advanced speakers around 5.8 years of French contact. Part of this time was spent in language courses, as well as L2 learners, in general, keep restricted environments for language interaction and communication, putting some questions in the real language exposition of L2 even in advanced speakers (McNamara, 2006). It would be interesting to apply L2 experiments in high advanced speakers which had at least 18 years of contact with a L2, as in general monolinguals have when tested in psycholinguistic experiments (Frenck-Mestre, 2006).

We hypothesized that close typological languages, as French and Portuguese, which share many similarities in the verbal inflectional system, allow a fast and large transfer from L1 to L2. This can be done because close languages share many mechanisms in the grammatical level which might be surfaced by rules of conversion in late bilinguals. While many rules are shared between both systems, many other have to be inhibited and others have to be learnt. The fast shift from declarative to procedural processing suggests that L2 speakers quickly adopt their morphological systems accordingly to their pre-existent knowledge in verbal inflection from L1.

Following Plato's problem in Bertrand Russel words: "How comes it that human being, whose contacts with the world are brief and personal and limited, are able to know as much as they do know?" (Chomsky, 1988, p.3), the poverty of stimuli problem can be obviously be extended to late L2 speakers, in our case, the verbal inflectional processing: How is it possible that late L2 speakers, who had brief contact with French verbs, are able to produce and recognize as much inflected verbs as they do? The answer seems to be just one, late L2 speakers are not storing each new inflected verb that they find, but they are encoding morphological rules for French verbal inflection. More than that, you can show a low frequency inflected French verb to a beginner bilingual which has BP as L1, such as for example the form *astreignait* 'he forced', which the stem has no reference at all in BP, ask the L2 speaker what this word means. L2 speakers will respond that they do not know what it means, but that it is something that (s)he used to do in the past. It means that L2 speakers processed the tense and agreement inflectional suffixes, and they know that it is a French verb inflected in the indicative imperfect past tense (i.e., [-ai-]<sub>past</sub>) and in the 3rd singular agreement (i.e., [-t]<sub>3rd, singular</sub>), but they do not know the stem which contains the lexical meaning with the semantic features.

Thus, it seems to be evidence that since early stages of late L2 acquisition, especially in the case of close typological languages, there is a large transfer from L1 to L2 regarding lexical forms, but most important grammatical processes underlined in both L1 and L2 which can be recycled from L1 for the processing of the L2 grammar (Quémart et al., 2012). Since L2 speakers have enough redundant representations stored they can proceduralize a rule for verbal inflection based in their L1 processes for verbal inflection. In contrast, there should have as well between close languages interference from L1 in the L2 (Frenck-Mestre, 2006; Osterhout et al., 2006), for example, BP speakers use the indicative simple past in L1, but have to inhibit and use the *passé composé* in French as L2, which in BP is a composed tense used for imperfective or interactive aspect. Also, BP speakers do not use the 2nd plural

agreement (i.e., BP: *vós falais*, FR: *vous parlez*, ‘you<sub>pl</sub> speak’), but the 3rd plural agreement (e.g., BP: *vocês falam* ~ ‘you<sub>pl</sub> speak’).

Reconsidering the L2 deficit and L1 interference as the main criteria to explain differences between L1 and L2 processing, these assumptions can also be extended to the differences between beginner and advanced speakers. Thus, it can be argued that beginner bilinguals have much more deficit on L2 because of the short and restricted exposition and use of L2, while advanced speakers already had more experience with L2, solving a series of gaps for L2 processing simple based on L2 exposition. Also, beginner bilinguals might have less executive control in the use of both L1 and L2, more dependence from L1 translation, and thus, much more L1 interference, resulting in less strength during the activation of L2 processing; in contrast, advanced bilinguals, which already has more time and exposition to L2, has a better executive control of the use of L1 and L2, and are less dependent from L1 translation during the processing of the L2 (Frenck-Mestre, 2006).

## 4.7 Morphological Mental Lexicon

Considering the syncretism between 1st and 2nd or 3rd singular persons and only different inflected forms, each French verb accounts five different agreements in five tenses (i.e., indicative present, imperfect past, and simple future; conditional present; and subjunctive present), totalizing at least 25 forms per verb. French has more than 8,000 verbs, let’s consider that a speaker knows only 25% of his/her mother tongue (2,000 verbs), then, if this speaker has all words stored as whole units in the mental lexicon, (s)he should have at least 50,000 forms stored with redundant lexical information between the 25 forms (and related forms, such as prefixed forms, e.g., *ouvrir/rouvrir* ‘to open/to reopen’) which share the same lexical morpheme, and highly redundant inflectional information between the 2,000 verbs which share almost the same set of inflected suffixes as functional morphemes. Differently, in a morpheme-based approach, the speaker have to store the 2,000 stems and possible allomorphic stems with rules of convergence between the semantic and/or phonological related forms, plus the 25 suffixes, resulting in 2,025 units to be stored; obviously, this second hypothesis have to be subserved by a system of phonological, morphological, and syntactic rules which drive the system and bind the operations for word (de)composition (Hankamer, 1992). Our results support the second hypothesis where inflected verbs are atomically represented in the mental lexicon through morphological rules of combination and allomorphy.

But how much redundant information in the mental lexicon it is needed to proceduralize an inflectional rule? The answer is simple: two. Let's say that a speaker learn his first form *parlez* 'you<sub>pl</sub> speak', then he learns a second form *parlons* 'we speak', he immediately can think "/paRl/ means to speak", but what about this variations in the end? Then he learns two new forms *jouez* 'you<sub>pl</sub> play' and *jouons* 'we play', and he can think "/ʒu/ means to play, /e/ means you<sub>pl</sub> and /ɔ̃/ means we". Therefore, it seems that since the speakers acquire the different two or three tense morphemes (i.e., [-ai-]<sub>past</sub>~[-i-]<sub>1st/2nd plural</sub>, [-r-]<sub>futur</sub>) and the five agreement morphemes (i.e., [-s]<sub>2nd singular</sub>, [-t]<sub>3rd singular</sub>, [-ons]<sub>1st plural</sub>, [-ez]<sub>2nd plural</sub>, [-ent]<sub>3rd plural</sub>) through redundant forms, the speakers already can proceduralize the inflectional verbal system, and all other forms that they found will provide positive evidence for the rule productivity. Afterwards, the task of the speakers is to learn as much stems and roots as they can to enlarge their vocabulary.

It is hard to imagine how PDP models would simulate the significant effects of the cumulative frequency, morphological operations, morphosyntactic features, morphology-related full masked priming, and ERP differences regarding the processing of lexical and functional morphemes. It seems that these results follow from natural assumptions of the underlined grammatical system in language phenomena. It is not trivial to realize which predictions PDP models would postulate for the simulation and comparison of the results between OB and OS verb types, as also how IML verb type would be rejected by the model. "If there were any truth to these doctrines, human being would be miserable creatures indeed, extremely limited in their capacities, unlike one another, mere reflections of some accidental experience" (Chomsky, 1988, p.162).

In what extend allomorphic stems may be considered as underlined and predictable morphophonological adjustments in the post-lexical component based on the specific language constraints, or considered as different pre-lexical representations in the mental lexicon (Foley, 1979; Frauenfelder & Lahiri, 1992) ? Allomorphic processes present many degrees of complexity in French, as evinced by its many different micro-classes (Kilani-Schoch & Dressler, 2005) and patterns of verbal conjugation (Bescherelle, 2006). Therefore, stem allomorphy varies in the kind of processes (i.e., deletion, insertion, and substitution) and the degree of complexity, e.g., a) *placer/plaçons* 'to place/we place', b) *écrire/écrivons* 'to write/we write', c) *joinder/joignons* 'to join/we join', d) *naître/naissons* 'to born/we born', e) *aller/vas* 'to go/you<sub>sg</sub> go' (Estivalet & Meunier, 2016). Beside suppletive forms and some exceptions, it appears that the largest part of these allomorphic processes is predictable based on French phonological constraints or morphophonological rules.



## 4.8 Morphophonologies

We note that in all experiments which we tested French 1st class regular words and 3rd class irregular words (i.e., Study 1, Study 2, Study3: Experiment 1, Study 4: Experiment 1, and Study 5), we always found that irregular verbs present longer latencies than regular verbs. This finding seems to rule out models such as the AAM and W&R which posits that known words in the former and irregular words in the latter should be recognized by the whole word route. This is an associative form-to-meaning mechanism and should present faster RTs than the decompositional route. Alternatively, the MM model proposes a route with sub-lexical representations, which could yield larger RTs from irregular words. We argue that our results do not need a second sub-lexical route to explain the differences between fully regular and irregular French verbs; these differences can be explained by a single-mechanism which considers allomorphic processes and competition in the stem formation. It means that even irregular verbs from the 3rd class are decomposed for word recognition, but present delayed RTs in function of specific allomorphic process and competition in the formation and selection of these allomorphic forms accordingly to the morphological context (de Diego Balaguer et al., 2006).

As introduced above, the EPP seems to obligate the formal realization of the subject of the sentence; clauses must contain a NP in the subject position, i.e., in the Spec of TP, or in the Spec of vP in languages in which subjects do not raise to TP. Thus, while French and English phonologically realize the EPP, other Romance languages can present undetermined subject and do not phonologically realize the subject. Thus, while other Romance languages realize the agreement morphosyntactic features in the inflectional verbal suffixes, French phonologically has cleaned the realization of these suffixes but obligated the production of the subject of the sentence. One can think that this agreement category is a weak category which even if expressed in the orthographic forms, has lost its phonological realization in French (Bybee, 1985; Kilani-Schoch & Dressler, 2005).

In Romance languages, verbs are generally distributed in three conjugational classes, with the largest number of types belonging to 1st class (i.e., Portuguese, Spanish: [ $\sqrt{\text{var}}$ ]; Catalan, Italian: [ $\sqrt{\text{vare}}$ ]; French: [ $\sqrt{\text{ver}}$ ]). The other classes are not necessarily irregular, but tend to contain fewer verb types of high token frequency. Verbal forms created by children acquiring French involve the use of the first class on verbs belonging to other classes in the adult language, they generalize not the 3rd class which has higher token frequency, but the 1st

class which has the highest type frequency, as shown in Table 6. Children overgeneralize the 1st class, as adults generally inflect new verbs in the 1st class (Bybee, 1995).

Table 6 - Count of verbs used by French children (Bybee, 1995).

## 4.9 Issues and Alternatives

It seems that there is a considerable intuitive appeal to the bottom-up strategy in word recognition, where linguistic stimuli is encoded by the peripheral sensorial system and delivered to the language domain-specific peripheral system (Henderson, 1992). Considering the modularity theory, language is a peripheral domain-specific module, and vision and auditory system are peripheral domain-general modules. Information from the latter can only feed central and other peripheral domain-specific modules, but cannot be feed by other modules (Fodor, 1983). It means that information from the visual and auditory SM system cannot suffer influence from any other module, but can only deliver general information to the other modules. In contrast, the language C-I system can receive and process information from other peripheral modules, as the SM, but cannot influence this modules.

In the OD model there are two types of representations, a peripheral file and central file, where the former has decomposed representations to match with sensorial input and the latter provide complete information about the word. It was proposed that for the prefix stripping, there should have a list of prefixes represented in the peripheral file for trigger prefix stripping, after, the stem can be naturally decomposed in the peripheral system based on the assumption that words are read from left-to-right holds (i.e., j, jo, jou<sub>stem</sub>, [jou]o, [jou]on, [jou]ons<sub>Agr</sub>, [[jou]<sub>stem</sub>[ons]<sub>Agr</sub>]<sub>word</sub>, *jouons* ‘we play’), allowing the access of the whole word by its stem in the central system (Taft & Forster, 1975; Taft, 1979).

One can think that since n-grams becomes activated, specific n-grams are encoded as morphemes based on their regularity and pertinence, triggering morphological decomposition,

and thus, morphemic representations are activated in the mental lexicon. But for this, affixes would have to be represented in the peripheral system (Taft, 1991). However, if we do not want to suppose representations in the peripheral SM, PDP models offer the suitable architecture to identify abstract phonological and orthographic forms from basic general orthographic and phonological features (Taft, 1994). Even more interesting, this probabilistic SM system based on local PDP architecture specialized in the processing of phonological and orthographic features of specific languages could deliver filtered and enveloped sequences of information to the C-I central system for language processing and interpretation. Then, the C-I system can decompose the form based in the core morphological representations in this language domain-specific system, and so on for morphological processing.

Interesting, models based on the W&P architecture have a tendency to postulate dual-routes for word recognition, where even productive and regular words of high frequency may be stored as whole forms in the mental lexicon, that is, since a word or productive rule is perceived as highly frequent, it should shift from the combinatorial activation to whole word storage (Bybee, 1995). In contrast, IP architecture would predict that since many words have redundant information to be stored, it may be proceduralized from the whole word representation to rule-based formation. But two basic questions remain: How humans account word frequency? How frequency is stored in the mental lexicon? Clearly, these question might be pursued from a realistic psycholinguistic perspective.

We note that the long debated between symbolic manipulation and PDP models has not finished, but seems to have changed the line of discussion. PDP models provided interesting insight in the sensory level of processing, while symbolic-manipulation provides better adequacy for linguistic explanation. Thus, these models do not need to be anymore concurrent and exclusive, but they may be complementary regarding the different levels of language processing (Caramazza, 1997; Hay & Baayen, 2005). When modeling the functioning of language processing, researches may think what levels are important for input recognition, and how these levels should interact in the brain systems.

Kilani-Schoch and Dressler (2005) propose that since a productive rule generate high frequent forms, they should be stored as whole forms and speakers should respond without hesitation, however, if speakers hesitate for a response, it can be that a) the word is not stored, b) the rule to produce the form is not productive, or c) there is competition between rules. These predictions are in agreement with (Bybee, 1985, p.7), “it is simple not necessary for human language users to segment every sequence into its minimal parts, because it is possible

to acquire, store and access complex chunks of material without segmentation. Rote processing, then, interacts with analytic processing”. We agree with predictions b) and c), however, we propose that even if a word has high frequency but is formed by a productive rule, this word will be naturally decomposed for word recognition.

## 4.10 Past, Present, Future

The present thesis included five studies on morphological processing of French inflected verbs, four with monolinguals (one coupled with EEG) and one with bilinguals. During the four years of thesis, other experiments were also applied and analyzed, but the results were not reported in this thesis. They were: a) an experiment with lexical decision task on French (pseudo)verbs with different structures (Estivalet & Meunier, 2016c), b) an offline experiment of written verbal production in French based on the presentation of discrete affixes, c) an online experiment with lexical decision task on French affixes (Estivalet & Meunier, 2015b), d) two masked priming experiments (42 ms and 52 ms of masked priming) in French derived words for triggering decomposition, e) a lexical decision task experiment on French verbs coupled with EEG (Estivalet & Meunier, 2016a).

Also, it was developed during the thesis the Brazilian Portuguese Lexicon (LexPorBR), which from our knowledge is the first word-based corpus from the BP (Estivalet & Meunier, 2015). To validate this corpus, in line with other lexicon projects (Balota et al., 2007; Ferrand et al., 2010; Keuleers et al., 2010, 2012), we applied a lexical decision task experiment on 1008 words and 1008 pseudowords from the Brazilian Portuguese Lexicon, the Mini Brazilian Portuguese Lexicon Project (MBPLP).

Finally, it was developed a computational modeling from the French and BP verbal system. The Morphological Decomposition Modeling (MDM) was developed in the R software (R Core Team, 2014) and was split in two modules, one for morphological acquisition and another for morphological processing in recognition and production. The module of acquisition split all visual input in n-grams, and morphemes are acquired through redundancy and consistency of n-grams in the presentation of a corpus of verbs. The recognition/production module decomposes sensorial input based on the morphological representations acquired and compute the morphosyntactic features present in a form; in pseudowords, it uses lower level representations, as trigrams and bigrams (Taft, 1991).

The main difficulty found in the development of this work was the abyss between the theoretical linguistics and the empirical psycholinguistics. While the former analyzes fine processes for phonological, morphological, syntactic, and semantic processing in an inductive perspective, the latter analyzes RTs, error rates, ERPs, ROIs, and inferential statistics in a deductive perspective (Marantz, 2005; Poeppel & Embick, 2005). But this was also the main challenge of this work and we believe to have approached the two domains, discussing how the empirical results can be explained by the linguistic theory, and what should be reviewed in the linguistic theory considering the empirical results.

One of the limits found in the experiments presented here is the difficulty for the selection of stimuli which match the lexical properties desired in the different experimental conditions of interest (Duyck, Desmet, Verbeke, & Brysbaert, 2004; New et al., 2004; New, Pallier, Ferrand, & Matos, 2001). It was overcome by different manners, such as the precise analyses of specific lexical characteristics for stimuli matching (Davis, 2005; Peereman & Content, 1999), the use of random stimuli selection from pre-filtered corpora (Forster, 2000), and the use of an automatic match program (van Casteren & Davis, 2007). In the same line, the difficulty in preparing the counterbalanced lists of stimuli presentation was surmounted using a specific program for pseudo-randomization accordingly to different experimental criteria (van Casteren & Davis, 2006). Finally, many statistical constraints were overcome exploring trivial and alternative analysis accordingly to the experimental design (Baayen, Davidson, & Bates, 2008; Baayen, 2008; Clark, 1973; Forster & Dickinson, 1976; Pollatsek & Well, 1995; Raaijmakers, Schrijnemakers, & Gremmen, 1999)

Regarding the results presented, many questions were unsolved and after this work, these questions are multiplied and acquired a deeper character. Nevertheless, we were limited in answering whereas allomorphic stems are separately but linked represented in the mental lexicon or if they are abstractly represented and driven by allomorphic rules. Perhaps a further masked priming experiment with four conditions of prime can help to solve this question: a) unrelated control, b) identity, c) allomorphic, and d) allomorphic violated, where the last condition blocks the application of the allomorphic rule.

Another unanswered question which actually remains for long time and have been discussed in psycholinguistics is: What exactly the P600 means in simple word lexical decision task? The P600 is known as an ERP which indicates syntactic reparation and verification (Coulson et al., 1998; Osterhout, 1999; Rodriguez-Fornells et al., 2001). Our perspective is that morphology is a sub-component of the syntactic processing; however, our

experiments explored single word presentation, without any syntactic context. Anywhere, in our EEG experiment, the RTs mean was 880 ms, long time after the P600 which was modulated by the different experimental conditions. We would like to say that the P600 indicated the morphological recombination phase where the word formation is verified for subsequent word recognition, fitting the three phases from the decompositional model which has been delineated here: N1-P2 for sensorial processing and decomposition, LAN-N400 for lexical and functional access and activation, and P600 for the recombination and verification, followed by motor responses. But the literature have proposed that this processes are not sequential and may finish in the M350/N400 (Fruchter & Marantz, 2015; Lau et al., 2008; Lavric et al., 2012; Zipse et al., 2006). To try to solve the significance of the P600 in single word lexical decision task, maybe, a delayed lexical decision task could be proposed; it is, participants should not perform their responses when they recognize the words but when allowed by the experiment. This could produce less noise and expectance in the participants' responses during the word processing.

Finally, a last limit in the bilingual experiments was the control of the level of proficiency in these populations. Bilinguals which are generally tested in psycholinguistic experiments have different personal relations with the L2, different learning strategies, different ways and situations in which they use L2. Most important, they have a short contact since adulthood with the L2 when tested, which is completely different from the monolingual psycholinguistic experiments with adults which had at least 18 years of massive language stimulation since babyhood. Therefore, we suggest that bilingual experiments should try to recruit advanced speakers with at least 18 years of L2 contact to more precisely observe neurocognitive and psycholinguistic aspects of language processing in late bilinguals.



## 5 Morphological Decomposition Model

“Morphological information has provided the greatest single source of data in the formulation and development of the theory of evolution and that even now, when the preponderance of work is experimental, the basis for interpretation in many areas of study remains the form and relationships of structures” (Everett Olson, 1910-1993)

After the presentation of the main theoretical background in the introduction section, the five empirical studies, and the general discussion above, in this section we sketch the main characteristics of the Morphological Decomposition Model (MDM) that has been delineated in this thesis for the morphological processing of French inflected verbs. It is presented in section 5.1 the functioning of the model in word recognition, 5.2 the morphological acquisition, 5.3 the French verbal structure, 5.4 the French verbal vocabulary items, 5.5 the French morphological rules, and 5.6 the last remarks about the MDM.

We will depart from the Halle (1973)’s architecture (Figure 10) and incorporate the theoretical assumptions from the DM (Figure 13) (Boeckx et al., 2014; Embick & Noyer, 2007; David Embick, 2015; Halle & Marantz, 1993, 1994; Harley & Noyer, 1999; Siddiqi, 2009). Then, we will consider the empirical results from the OD model (Figure 11) (Taft & Forster, 1975; Taft, 1979, 1991, 2004) and TL models (Figure 21) (Allen & Badecker, 1999, 2002; Caramazza, 1997; Crepaldi et al., 2010; de Diego Balaguer et al., 2006; Marslen-Wilson & Tyler, 2007). Afterwards, we will consider the recent findings and consequences from the SR model (Figure 14) (Embick et al., 2001; Fruchter & Marantz, 2015; Stockall et al., 2004). Our results are in line with models which split the SM system from the C-I system. Concerning the SM, we will depart from lower level of activations in line with the NDL model with non-interactive connectionist architecture (Baayen et al., 2011; McClelland & Rumelhart, 1981).

Our assumptions are developed based on the empirical results from Romance language studies. In these languages, word formation is typically analyzed by means of combinations between morphemes, thus, we find free morphemes which are realized as words and bound morphemes which should be combined to form words (Beard, 1995; Katamba, 1993; Spencer, 1991). Romance languages are prototypical cases where words are formed by a stem lexical



morpheme in the left side and suffixes as functional morphemes in the right side. While in derivation it has been considered which morphemes and processes are productive or non-productive (Bybee, 1985; Ford, Davis, & Marslen-Wilson, 2010; Marslen-Wilson et al., 1994), in inflection the discussion is around regular and irregular forms and processes (Clahsen, 1999; Marantz, 2016; Orsolini & Marslen-Wilson, 1997; Pinker, 1991), as shown in Figure 32.

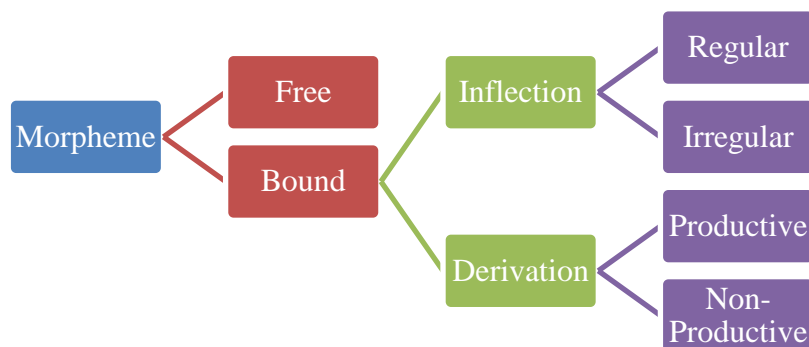


Figure 32 – Schema with the main divisions of morphology.

## 5.1 Model Functioning

The MDM considers two basic modules for language processing accordingly to the SMT: a SM system and a C-I system. The former is a domain-general component which processes all kind of acoustic and visual information for language recognition, and motor control for language production through speech or sign language. Concerning the auditory and visual input systems, the SM is a peripheral module which can only process external input and feed information to other modules, but cannot be feed by them (Fodor, 1983). The C-I is an internal system which process and interprets language accordingly to general principles and specific parameters, creating the conceptual structure and interpreting the intensions of communication and language use (Chomsky, 1995).

Therefore, in visual word recognition, the sensorial input first activated the primary visual cortex in the occipital lobe, and orthographic features are processed mainly in the left VWFA in the fusiform gyrus (Dehaene & Cohen, 2011; Dehaene et al., 2002). In the auditory word recognition, the phonetic features are processed bilaterally in the STG (Hickok & Poeppel, 2007; Mesgarani et al., 2014). Thus, the auditory and orthographic sensorial inputs are encoded by their basic phonetic and orthographic features in the STG and VWFA,

respectively, as shown in Figure 33. Graphemes can activate phonemes in a lower level, and the orthographic form activates the phonological form in a higher level, and vice-versa. We note that this schema represent general auditory and visual SM processes, but since there is any information which resembles to language, such as the activation of the phonetic and orthographic features, this triggers low levels of language processing towards the isolation of interpretative information based on this features.

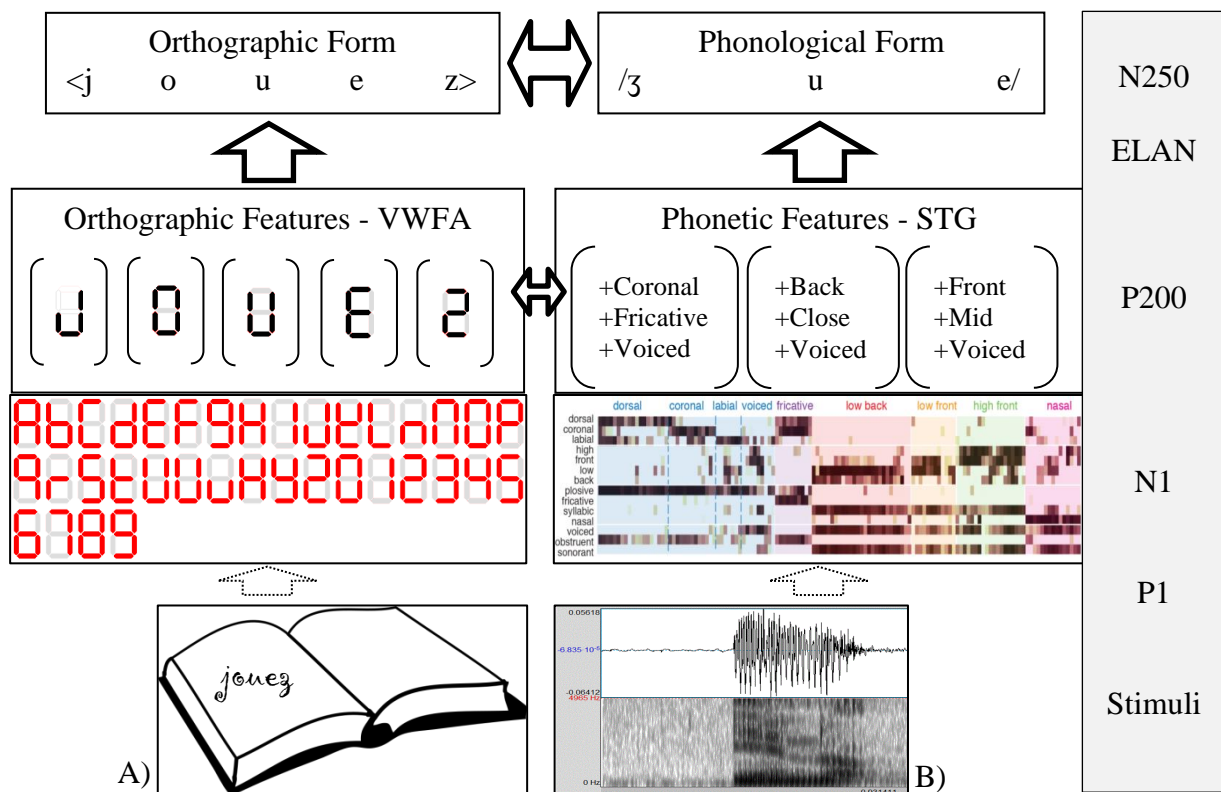


Figure 33 – SM: auditory and visual stimuli activate the phonological and orthographic features which determine the phonological and orthographic forms for linguistic processing. A) Orthographic features encoded in the VWFA (Dehaene et al., 2005). B) Phonetic features encoded in the STG (Mesgarani et al., 2014)

After this basic auditory/visual encoding of features for the construction of the orthographic/phonological form, the information might be transferred from the SM module to the C-I module for language processing. Apparently, this hub which receives encoded sensorial information and interfaces with the lexical access is localized in the MTG and the Wernicke's area (Bozic et al., 2007; Carreiras et al., 2014; Hickok & Poeppel, 2004), which

are structurally, functionally, and dynamically connected to the pre-motor cortex and Broca's area by two dorsal pathways of fibers, and connected to the inferior frontal cortex by the ventral pathway (Figure 9) (Berwick et al., 2013; Carreiras et al., 2009; Friederici, 2002; Hickok & Poeppel, 2004; Marslen-Wilson & Tyler, 2007).

The internal C-I system can dynamically decompose any form from a left-to-right in a COHORT perspective based on the morphological representations in the mental lexicon (i.e., Orthography: j, jo, jou<sub>stem</sub>, [jou]e, [jou]eZ<sub>Agr</sub>, [[jou]<sub>stem</sub>[eZ]<sub>Agr</sub>]<sub>word</sub>; Phonology: /ʒ/, /ʒu/<sub>stem</sub>, /ʒu<sub>stem</sub>e<sub>Agr</sub>/<sub>word</sub>; *jouez* 'you<sub>pl</sub> play') (Marslen-Wilson, 1987; Taft, 1991). Taking the DM which distributes the lexicon in three lists, this phonological/orthographic form is decomposed triggered by the representations of the Vocabulary Items in List 2. Thus, by means of Morphological Operations, these Features are checked in List 1; finally, by means of the Syntactic Operations interpreted the Logical Form. This information is enriched by the general knowledge of the Encyclopedia in each phase and the Meaning of a word is identified (Boeckx et al., 2014). We can note the syntax-all-the-way-down assumption from the DM, where words are processed by the syntactic component (Embick & Noyer, 2001; Siddiqi, 2009)

In the case of our lexical decision experiments in single word recognition of French inflected verbs, this whole process can be simplified. The phonological/orthographic form is decomposed triggered by the morphological vocabulary items representations of the lexical morpheme and functional morphemes. Thus, morphological operations are performed, in line with the merge operation, which combine two constituents in another one (Marantz, 1984). Then, the semantic and morphosyntactic features are activated and the logical form check the morphotactics combination, enriching it with the encyclopedia knowledge in each phase, resulting in the word recognition or rejection.

We note that theoretical linguistic models are generally conceptualized from the speaker perspective, and the word recognition can be taken from two perspectives: the reverse way from the production processes or following the same production processes for language interpretation. Importantly, in the DM framework, the reverse way remake the production processes, converging for a general language processing, nevertheless, production or recognition have different processes in each phase. The general C-I system sketched above is presented in Figure 34.

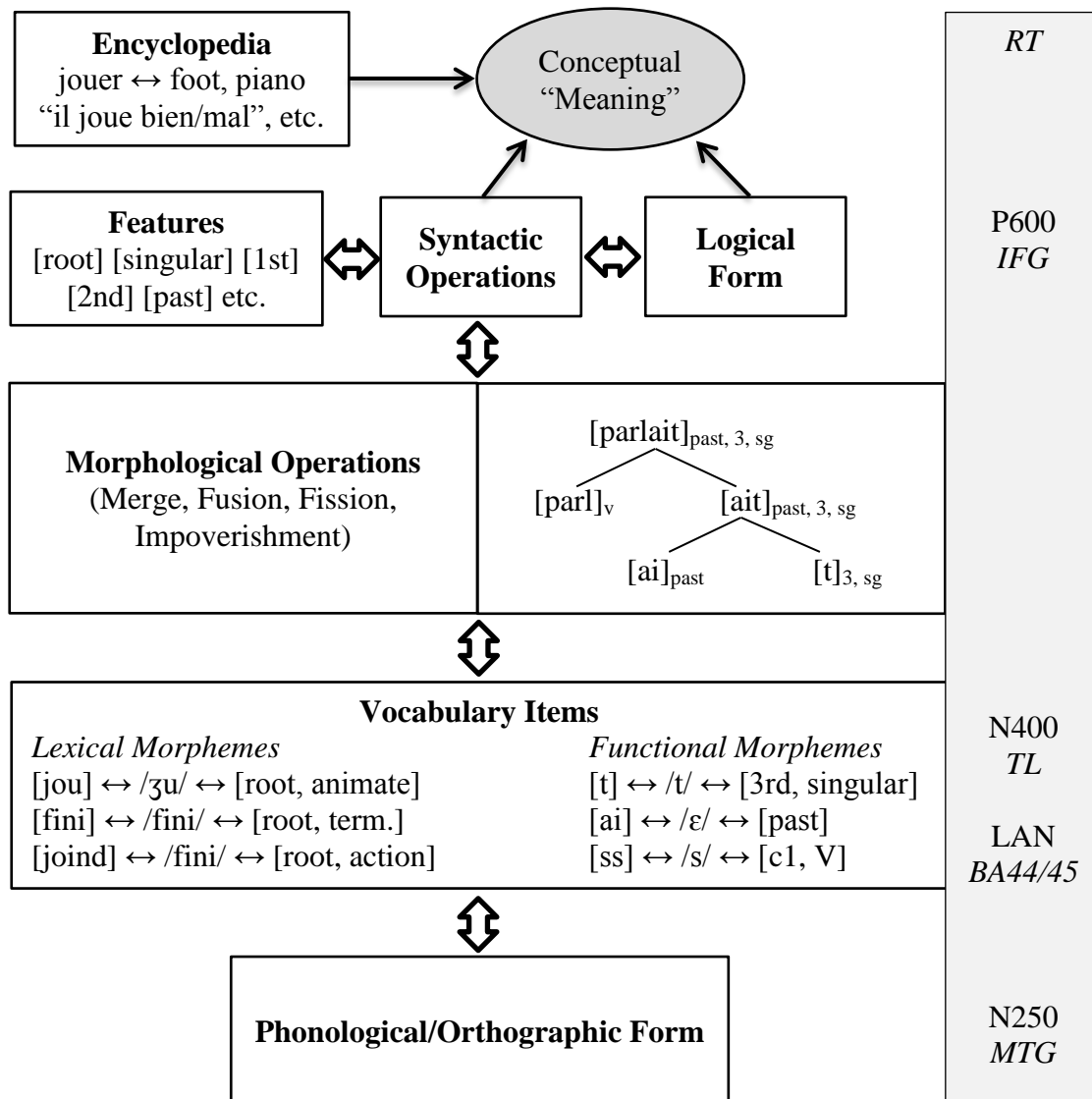


Figure 34 – MDM architecture. Adapted from Siddiqi (2009).

## 5.2 Morphological Acquisition

Bybee (1985) presented an exhaustive survey of verbal inflection in different languages with different typologies which reveals that inflectional meanings for verbal categories broadly fit into the conceptual theoretical categories identified by linguists. These categories present recurrent morphological markers for the different basic categories, as defined in the following hierarchy: aspect > tense > mood > person > number. We note that the MM strongly consider these hierarchy of inflectional categories to determine the morphotactics in word formation (Fabri et al., 1995; Wunderlich & Fabri, 1995; Wunderlich, 1996). Thus, “when these categories are affixed to the verb, they tend to occur with the categories that have the greatest semantic relevance to the verb closest to the stem, that is, from the stem outward:

aspect, tense, mood, person/number. The categories closest to the stem also show greater morphophonological fusion with the stem, as manifested by the mutual conditioning of allomorphy between stem and affix” (Bybee, 2000, p.804).

It should be considered that these categories are naturally encoded by the language component in verbal inflection. It does not mean that all languages adopt all these categories, but that different languages differently develop specific marker as affixes to express some of these categories in this hierarchy. Thus, in morphological acquisition, more than the roots, stems, and affixes, speakers acquire a series of semantic and morphosyntactic features, as also the morphotactics which is the order of combination between morphemes (Blevins, 2006). Regarding exclusively the systematic morphosyntactic features activated by the French verbal inflectional suffixes, the structural paradigms presented in Tables 1 and 2 can be reduced to their morphosyntactic features accordingly to the underspecified hypothesis (Penke et al., 2004). This representation respect the hierarchy of the categories presented below and avoid syncretism between the same features being expressed by different inflectional suffixes, as also the syncretism between the same forms of inflectional suffixes which expresses different morphosyntactic features, as shown in Table 7.

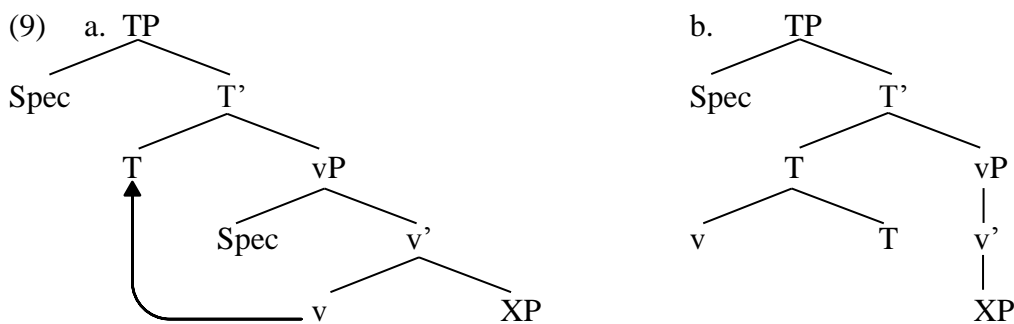
Morphological Nodes		Class	Tense	Agreement								
Features/Suffixes		e a i	ai i r ss	s ai as t a ons ez ent ont								
Class	1	+ +										
	2											
Tense	Present											
	Imperfect		+ +									
	Future											+
	Conditional		+ + +									
	Subj. Pres.	+		+								
Person	1			+	+							+
	2			+		+						+
	3						+	+				+
Number	Singular	+			+	+	+	+	+			
	Plural			+						+	+	+

Table 7 – Underspecified morphosyntactic features from the French verbal inflectional suffixes (Penke et al., 2004; Wunderlich & Fabri, 1995). Grey marks represent features from adjacent categories.

## 5.3 French Word structure

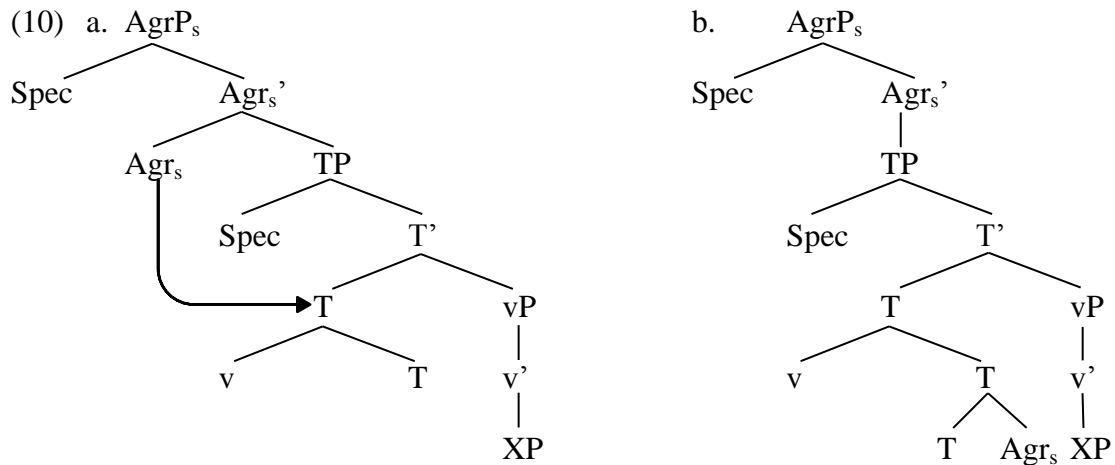
The Spell-Out operation is the point in the syntactic derivation where the phonetic production is realized, it means, when the linguistic structures are ready to be externalized. Its position in the syntactic derivation has been one of the discussed differences between languages; while French applies the spell-out after v-raising, English applies before v-raising, thus, PF conditions reflecting morphological properties must force v-raising in French but not in English. Accordingly to Pollock (1989), French has strong agreement, forcing the overt raising of the verb, while English has weak agreement, blocking it. Thus, after the v-features are checked, its features disappears, thus, if the v does not raises overtly, the features survive to the PF and it crashes, because they are not phonetic features (Chomsky, 1993).

Moving to a linguistic analysis from the French verb, we should start from the structure presented in (2) in the SMT (Chomsky, 1993). We are firstly concerned with the tense (T) node, thus, we do not consider the CP and AgrP morphological nodes. The main verb (v) is raised to the tense (T) by merge operation as (9a), patterning the final form with tense, resulting in the structure (9b) (Halle & Marantz, 1993).

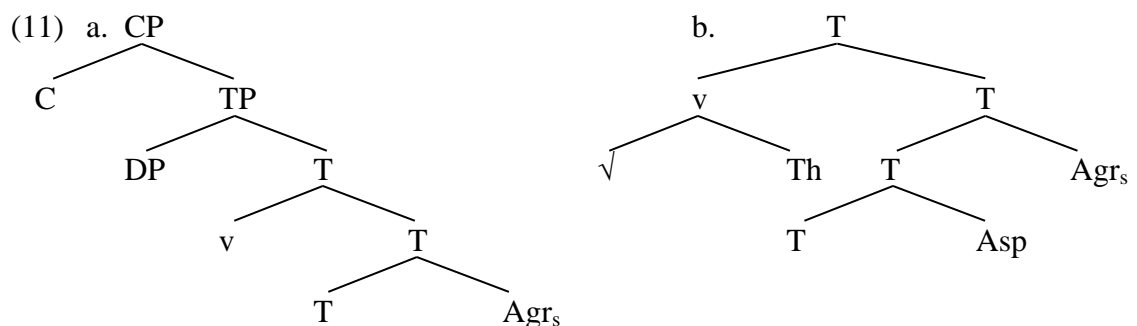


It should be noted that for example, while in English it is the tense morpheme that is lowered for adjoining the verb, in Romance languages, is it the verb that is moved to adjoin the tense node, which allow the introduction of an adverb between the verb and its object for example (e.g., *Jean aime beaucoup Marie* ‘John loves Mary a lot’) (Emonds, 1978). The next step is to introduce the agreement morpheme in the verbal structure for the activation of the phi-features (den Dikken, 2011). The subject agreement is above the tense node as (6a), thus, it is adjoined to the tense node by overt lowering movement, because the morphosyntactic features from agreement are pronounced in the spell-out, accordingly to (6b) (Halle & Marantz, 1994). We note that agreement proceeds in at least two steps, agreement is defined

in syntax, but implemented in the post-syntactic component, where the information affected is only available at this point of the (Bonet, 2013).



Afterwards, it is possible to clear the indexed traces left above the tense phrase (TP) and verbal phrase (vP), directly adjoin the CP, and simplify the structure resulting in a similar representation than Halle and Marantz (1993), but with the inflection nodes within the T node, accordingly to the syntactic and morphological hierarchical structure in Romance languages (Embick & Halle, 2005; Halle & Marantz, 1994). We note that the vP node have to be reconstructed in sentences where there the verbal object agreement ( $\text{Agr}_o$ ) takes place; it could, but was not included in the word morphological structure because the object agreement is dependent from the pre-verbal object movement. These adjustments results in the general structure presented in (7a).



In many in many languages such as Italian (Orsolini & Marslen-Wilson, 1997), Latin (Aronoff, 1994), Portuguese (Villalva, 1994), Russian (Halle, 1990), Spanish (Bermúdez-

Otero, 2013), among others, stems have a theme vowel (Th) which has no syntactic or semantic role, but verbal distribution in the different classes and phonological role for the merge between stems and inflectional suffixes. It has been argued that theme vowel, case, and agreement morphemes should be added to heads at the MS in accordance to language parameters (Marantz, 1984). Therefore, the theme vowel should be introduced as a morpheme in the verbal morphological word structure. The theme vowel is not an inflectional suffix, thus, it is not introduced within the tense node (T) but within the v node for the stem formation in the combination with the root ( $\sqrt{\text{ }}$ ) (Oltra-Massuet & Marantz, 1999).

Finally, we should only insert the aspect (Asp) morpheme for the construction of complex modes as for example the conditional present (e.g.,  $[[[\text{par}]_{\sqrt{}}[\text{e}]_{\text{Th}}]_{\text{v}}[[\text{r}]_{\text{T}}[\text{i}]_{\text{Asp}}]_{\text{T}}[\text{ons}]_{\text{Agr}}]_{\text{T}}$  ‘we would speak’), resulting in the French verbal hierarchical structure as (7b), which resembles to that of Spanish verbs (Arregi, 2000). The aspect morpheme will have the same role than the Th in the phonological computation, as discussed below. To summarize the verbal formation from the general syntactic structure in (2); first, there a covert raising of the main verbal node (v) to the tense node (T) (5); second, there is an overt lowering from the subject agreement ( $\text{Agr}_s$ ) to the tense node (T) (6); third, there is the linearization of the word hierarchical structure with the clause phrase (CP) and erasing of the indexed traces (7a); and four, there is the insertion of the theme vowel (Th) to correspond to the stem formation processes in Romance languages, and the insertion of the aspect morpheme to create more complex modes, as the conditional and subjunctive.

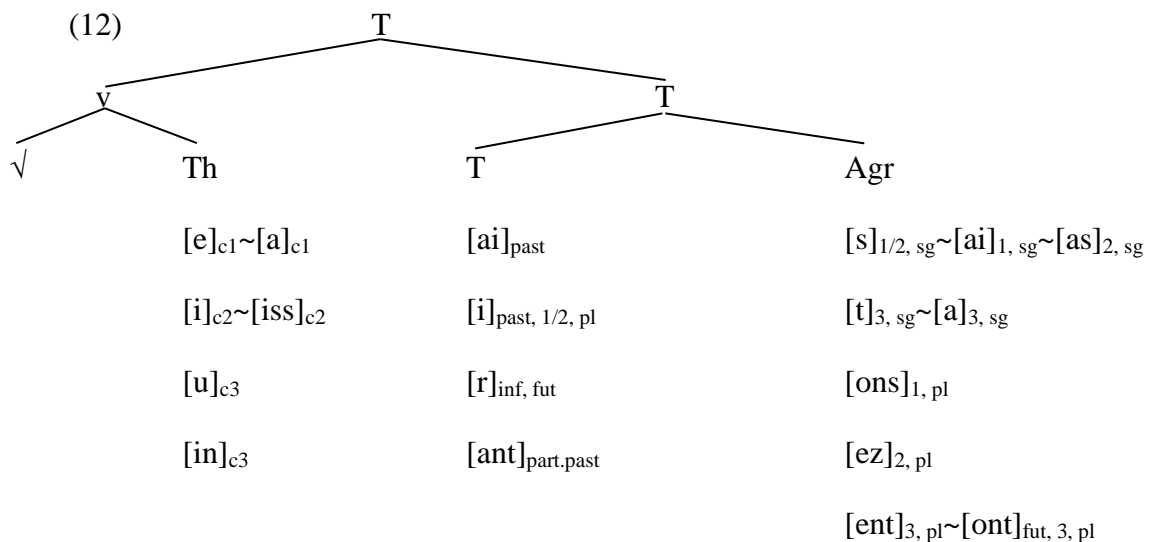
## 5.4 French Vocabulary Items

Considering the theoretical analyses and the empirical results presented above, we would like to propose the verbal French morphemes necessary for the functioning of its verbal inflectional system. We based our analyses in the DM, which considers in the List 2 the Vocabulary Items of the language (Harley & Noyer, 1999). The Vocabulary Items are generally presented in terms of phonological insertions, but since our empirical research was developed in the visual orthographic modality, and French presence an idiosyncratic relation between orthography and phonology, we present below a summarized version of the orthographic morphemes in Table 7, based on Tables 1, 2, and 6. A complete table with all the orthographic vocabulary items and orthographic structure insertion is presented in Appendix C, as also a complete table with all the phonological vocabulary items and



phonological structure insertion is presented in Appendix D. These two versions of the French verbal system obviously overlap in many clusters, but allow fine distinctions in other ones.

It is important to keep in mind that DM considers zero morpheme as the default, which is in close relation to the underspecified hypothesis (Noyer, 2006; Penke et al., 2004). In many languages “there is no rule at all realizing the 3rd singular forms, in many inflectional systems, 3rd person singular is the default P[erson]/N[umber] specification. In Italian, as in many other languages, it receives no special marker. In other words, it is represented by a zero morph” (Spencer, 1991, p.218). The Elsewhere Principle is explored to regulate the use of the last specified vocabulary entry that does not constitute an item with complete morphosyntactic features expressed on the terminal node, it means, it allows the use of the standard vocabulary item, which is the less specified one in morphosyntactic features (Arregi & Nevins, 2013)



nb	Morpheme	Orthography	Phonology	Features	Node
1	[-e-] ↔ [c1]	<e>   <a>	/ə/   /a/	[c1]	[Th]
2	[-e] ↔ [sg]	<e>	/ə/	[sg]	[Agr]
3	[-i] ↔ [c2]	<i>   <iss>	/s/   /is/	[c2]	[Th]
4	[-u] ↔ [c3]	<u>	/y/	[c3]	[Th]
5	[-in] ↔ [c3]	<in>	/ɛ̃/	[c3]	[Th]
6	[-s] ↔ [1/2, sg]	<s>	/z/	[1/2, sg]	[Agr]
7	[-t] ↔ [3, sg]	<t>	/t/	[3, sg]	[Agr]
8	[-ai] ↔ [1, sg]	<ai>	/ɛ/	[1, sg]	T[Agr]
9	[-as] ↔ [2, sg]	<as>	/az/	[2, sg]	T[Agr]
10	[-a] ↔ [3, sg]	<a>	/a/	[3, sgl]	T[Agr]
11	[-ons] ↔ [1, pl]	<ons>	/ɔ̃z/	[1, pl]	[Agr]
12	[-ez] ↔ [2, pl]	<ez>	/ez/	[2, pl]	[Agr]
13	[-ent] ↔ [3, pl]	<ent>	/ɑ̃t/	[3, pl]	[Agr]
14	[-ont] ↔ [fut, 3, pl]	<ont>	/ɔ̃t/	[fut, 3, pl]	[[T][Agr]]
16	[-ai-] ↔ [past]	<ai>	/ɛ/	[past]	[T]
15	[-i-] ↔ [past, 1/2, pl]	<i>	/j/	[past, 1/2, pl]	[[T][Agr]]
17	[-r-] ↔ [inf]	<r>   <rr>	/R/	[fut]	[T]
19	[-ant] ↔ [part.pres]	<ant>	/ɑ̃t/	[part.pres]	[T]

Table 8 – Summary of the French vocabulary items in verbal inflection.

## 5.5 Morphological Rules

Initially, Halle and Marantz (1993) proposed that competition between vocabulary items should be solved by simple order of insertion. Alternatively, Harley and Noyer (1999) employed the Universal Hierarchy of Features discussed above (i.e., aspect > tense > mood > person > number) (Bybee, 1985; Wunderlich, 1996), where vocabulary items which realize higher features are preferred. Another important morphological operation is

'impoverishment', which is a simple deletion of a morphosyntactic features from the vocabulary items in certain contexts. Then, when specific features are deleted, the competition for the insertion of the vocabulary item cannot occur, and a less specified item will be inserted instead (Noyer, 2006).

Accordingly to Chomsky (1993, p.27) "the main verb typically 'picks up' the features of Tense and Agr (in fact, both Agr<sub>s</sub> and Agr<sub>o</sub> in the general case), adjoining to an inflectional element I to form [ $\nu$  I]. There are two ways to interpret the process, for a lexical element  $\alpha$ . One is to take  $\alpha$  to be a bare, uninflected form; PF rules are then designed to interpret the abstract complex [ $\alpha$  I] as a single inflected phonological word. The other approach is to take  $\alpha$  to have inflectional features in the lexicon as an intrinsic property (in the spirit of lexicalist phonology); these features are then checked against the inflectional element I in the complex [ $\alpha$  I]. If the features of  $\alpha$  and I match, I disappears and  $\alpha$  enters the PF component under Spell-Out; if they conflict, I remains and the derivation crashes at PF".

Following this principle, in the Romance inflectional system, the stem should be checked against the tense node containing the tense and agreement inflectional suffixes. Therefore, the stem must be subjected to PF rules to be adjusted to the merge operation between the stem and suffixes. Adopting the Lexical Phonology position, root have a lexical phonological representation and the whole word formation is subjected to readjustment rules after each phase of the syntactic derivation. In this sense, we propose the set of rules below which seems to hold for the large part of the French verbal inflectional system.

nb	Morphology	Phonology	Type
1	$[\sqrt{c}] \rightarrow [\sqrt{ç}] / \_ [a o]$	$/\sqrt{s}/ \rightarrow / \sqrt{s} / \_ [a o]$	Assimilation
2	$[\sqrt{g}] \rightarrow [\sqrt{ge}] / \_ [a o]$	$/\sqrt{ʒ}/ \rightarrow / \sqrt{ʒ} / \_ [a o]$	Assimilation
3	$[\sqrt{i}] \rightarrow [\sqrt{iss}] / \_ V$	$/\sqrt{i}/ \rightarrow / \sqrt{is} / \_ [vocalic]$	Insertion
4	$[\sqrt{i}] \rightarrow [\sqrt{is \sqrt{iv}}] / \_ V$	$/\sqrt{i}/ \rightarrow / \sqrt{iz \sqrt{iv}} / \_ [vocalic]$	Insertion
5	$[\sqrt{in}] \rightarrow [\sqrt{ign}] / \_ V$	$/\sqrt{\tilde{e}}/ \rightarrow / \sqrt{\tilde{e}\eta} / \_ [vocalic]$	Substitution
6	$[ai] \rightarrow [i] / \_ V$	$/E/ \rightarrow /j/ / \_ [vocalic]$	Assimilation
7	$[ent] \rightarrow [ont] / [r] \_$	$/\tilde{a}/ \rightarrow / \tilde{ɔ} / / R / \_$	Assimilation
8	$[s] \rightarrow [x] / [\sqrt{eu}] \_$	$/z/ \rightarrow /z/ / / \sqrt{\text{œ}} / \_$	Assimilation
9	$[\alpha] \rightarrow \emptyset / [c1, 1/3, sg]$	$/z/ \rightarrow \emptyset / / \text{ə} / \_$	Deletion
10	$[\sqrt{e}] \rightarrow [\sqrt{e}]_{\text{stress}} / \_ \#   \_ \sigma \sigma \#$	$/e/ \rightarrow / \varepsilon / / \_ \#   \_ \sigma \sigma \#$	Stress
11	$[\sqrt{o}] \rightarrow [\sqrt{o}]_{\text{stress}} / \_ \#   \_ \sigma \sigma \#$	$/o/ \rightarrow / \text{ɔ} / / \_ \#   \_ \sigma \sigma \#$	Stress

Table 9 – Main morphological and phonological rules to hold the French inflectional system.

## 5.6 Last Remarks

We present first the general French verbal structure and the possible discrete phonemes which can be realized in each morphological node. We considered in these representations a maximal atomic decomposition hypothesis, where each phoneme, letter, morpheme, and morphosyntactic feature has to be realized in a different morphological node. Therefore, adopting Oltra-Massuet and Marantz (1999)' assumptions, actually each morphological node can be derived in a consonantal feet and a theme vowel feet, it means that complex cumulative morphemes, which generally present more phonological/orthographic material, can even be decomposed in their phonemic constituents. But before that, we would like to make some remarks about the French verbal inflectional system.

French present only one phonological insertion, it means, even if an inflected verb can have three inflectional suffixes, they are merged in only one syllable (e.g., <parlerions> ↔ /,parlə'Rjɔ̃/ 'we would speak'), thus, the single phonological syllable /Rjɔ̃/ amalgamate the [r]future, [i]past, and [ons]1st, plural morphemes. The only letters which can be the right word boundary in French inflected verbs are <s>, <z>, and <t>, where in rare juncture and liaison

cases can produce the phonemes /z/ for the former two letters and /t/ for the latter letter. Thus, it becomes clear that these last /z/ (i.e., <s>~<z>) represents the 1st and 2nd persons (i.e., [s], [on[s]], [e[z]]) and the /t/ represents the 3rd persons (i.e., [t], [en[t]]~[on[t]]).

Interestingly, the verb *être* ‘to be’ does not have the indicative present 1st plural form with the regular vocalic agreement morpheme [-ons] as all other verbs, but kept the indicative simple past consonantal agreement [-mes] (e.g., *nous sommes* ‘we are’). In the same line, the verbs *être* ‘to be’, *faire* ‘to do’, and *dire* ‘to say’ do not have the indicative present 2nd plural forms with the regular vocalic agreement morpheme [-ez], but kept the indicative simple past consonantal agreement [-tes] (e.g., *vous êtes* ‘you<sub>pl</sub> are’, *vous faites* ‘you<sub>pl</sub> do’, *vous dites* ‘you<sub>pl</sub> say’). What is important to note is that these agreement suffixes from the indicative simple past are consonantal, and thus do not attract the main stress which remains in the stem as rhizotonic forms. Also, the verbs *être* ‘to be’, *avoir* ‘to have’, *aller* ‘to go’, and *faire* ‘to do’ do not have the indicative present 3rd plural forms with the regular consonantal agreement morpheme [-ent], but with the vocalic agreement [-ont] (e.g., *ils sont* ‘they are’, *ils ont* ‘they do’, *ils vont* ‘they go’, *ils font* ‘they do’), reducing the stem for the only first letter and attracting the main stress to the inflectional suffix as arhizotonic forms (Kilani-Schoch & Dressler, 2005).

In this sense, we can find evidence that the traces left behind by the morphological operations are not pronounced, but are present in the mental representation of the sentence. These traces are processed by the language component to compute the structure of the sentence, satisfying the binding conditions, but they are not pronounced by the SM system because they do not contain phonetic features. Thus, the traces are visible by the mental representations, but do not send any signal to the externalization mechanism (Chomsky, 1988).

It becomes clear that the architecture of the MDM presented above and the DM theory resembles a lot with the Tripartite Representation architecture. Both theories seem to distribute the linguistic levels in different representations. While the Tripartite Representation theory clearly stipulates the syntactic, phonological, and conceptual parallel representations linked by rules of interface, the DM states the morphosyntactic features, vocabulary items, and encyclopedia, respectively. Therefore, the main difference between these two theories is that the DM proposes syntax all the way down with pre-lexical decomposition and late phonological insertion (Fruchter & Marantz, 2015; Halle & Marantz, 1993; Harley & Noyer, 1999; Siddiqi, 2009), while the Tripartite Representation keeps the Full-Entry Hypothesis and

propose a post-lexical morphological processing in the interface between the parallel representations (Culicover & Jackendoff, 2006; Jackendoff, 1997, 2002)

In contrast to the CM, our assumptions are that there is no need to have whole word representations in the mental lexicon. Actually, there is not any problem if all the words are stored and accessed through decompositional mechanisms, and there is no complex representations stored in the mental lexicon. The high productivity of affixes, morphophonological, morphographic, and allomorphic processes assures that all conceptual representations can be activated from minimal and atomic constituents in language processing. In the same way that a sentence is composed by different word with variable hierarchical relations between them, words are composed of morphemes and sub-lexical representations which define the conceptual representations to be contextually associated.



## 6 Conclusions

“What exactly is this idea to use sounds and letters to linearize thoughts?”

This thesis presented an introduction about the morphological processing and word recognition, followed by five chapters containing five different psycholinguistic empirical studies exploring the visual word recognition of French inflected verbs. Then, these results were discussed in the perspective of psycholinguistic, neurolinguistic, and linguistic domains and we presented a psycholinguistic model of word recognition with a single-mechanism of pre-lexical morphological decomposition, with the focus in the inflection of French verbs.

The present results are coherent between the different studies and experiments performed in this thesis and suggest that French inflected verbs are decomposed for word recognition. Apparently, all French verbs from the 1st, 2nd, and 3rd classes are decomposed for the processing of the lexical and functional morphemes (Beard, 1995; de Diego Balaguer et al., 2006). Our results did not indicate the necessity to postulate a whole word route for lexical access. We argue that a single-mechanism model with morphological decomposition can hold the complete French verbal system (Meunier & Marslen-Wilson, 2004).

Our results are in line with models of word recognition which assumes that words are decomposed pre-lexically for morphological processing, and the whole form is computed later (Forster, 1992; Pinker, 1991). Verbal inflection is the prototypical case where a lemma (i.e., the infinitive verbal form in the case of Romance languages), can be inflected in many different lexemes (inflected forms in tense and agreement conjugations). French has 48 forms per verb (i.e., 25 productive) and they do not need to be stored as whole units in the mental lexicon. A series of regularities in the combinations between stems and suffixes allow a much more dynamic system based on simple rules of combination and phonological adjustment (Di Sciullo & Williams, 1988; Halle & Marantz, 1993; Siddiqi, 2009).

Transposing the border of the morphological processing domain, the idea is that the cognitive system may store the information in their minimal atomic representations. It seems more coherent that the lexicon stores features which are abstractly defined than that it stores complex whole representations. The former hypothesis results in large redundancy between the information stored, in the former, only minimal features are stored and the relations between them determines the rules of computation for conceptual representation. For example,



do we have one whole instruction to drink a glass of water? Or we 1) take the glass, 2) bring the glass to the mouth, 3) turn the glass, 4) return the glass, and 5) leave the glass? If the answer is the former, the only thing you can do with this knowledge is to drink water. In the latter, you can recursively adapt your motor syntax after instruction 1 to give a glass of water to somebody, and so on. Where are the representations? A neuron spike or does not spike, and it is the simplest manner to approach the biological functioning of the brain from the psychological reality of the language representations. Thus, a feature can be specified or not.

In the MDM, we tried to make clear the separation between the domain-general SM system and the domain-specific C-I system. Apparently, in a lower sensorial level of processing, humans and baboons do the same task for the recognition of English words and nonwords. However, baboons, do not have a developed internal C-I system linked to orthographic representations. Therefore, what humans do in lexical decision task may be more than a simple probabilistic activation of a form-to-meaning. To decide the existence of a word, the brain has to identify a specific phonological/orthographic form from their features, the grammatical category of this form, the semantic features of the word provided by its root, morphosyntactic features provided by affixes, and finally has to verify if the phonological and orthographic form of this words are in agreement with the language constraints. The word /,alo'moRf/ exists in French and English, but that the word <alomorfe> does not. The latter is the BP orthographic form from the word 'allomorph', which cannot be a French or English word. Recognizing an existent word is a complex task which involves different levels of processing. Quite radical, there is no means to store complex words as whole units.

Finally, our results allow us to conclude that all French inflected verbs are pre-lexically morphologically decomposed during visual word recognition. During reading, orthographic forms are processed by the visual system which delivers information to the internal language system. Thus, these forms are decomposed in lexical and functional morphemes based on the morphemic representations. It seems that lexical morphemes are stored in the left temporal lobe while functional morphemes in anterior regions. The stem provides the general meaning, the tense morpheme specify the situational-intention, and the agreement morpheme realizes the syntactic information. Bilinguals with close L1 and L2 seems to quickly transfer grammatical information, as also lexical information in verbal inflection of Romance languages. Beginner and advanced bilinguals present different lexical frequencies, but no different processes than native speakers. To finish, morphological processing is an avenue for the investigation of the mental representations and processing, and this thesis present interesting reflections in the related fields.

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# Appendix A

**COMITE DE PROTECTION  
DES PERSONNES SUD-EST II  
GROUPEMENT HOSPITALIER EST**

Bâtiment Pinel  
59 Boulevard Pinel  
69500 BRON  
Tél : 04.27.85.62.46  
Fax : 04.27.85.80.85  
Emails : [info@cppsudest2.fr](mailto:info@cppsudest2.fr)  
[francoise.leclet@chu-lyon.fr](mailto:francoise.leclet@chu-lyon.fr)  
Site internet : <http://www.cppsudest2.fr>

Lyon, le 9 Octobre 2015

Monsieur Gustavo L. ESTIVALET  
Laboratoire sur le langage, le cerveau  
et la cognition - L2C2  
INSTITUT DES SCIENCES COGNITIVES  
CNRS/UCBL UMR 5304  
67 Boulevard Pinel  
69675 BRON CEDEX

Réf : CAL n° 2015-56


Monsieur,

Le Comité de Protection des Personnes SUD-EST II, lors de la séance du 7 Octobre 2015, a pris connaissance de votre courrier, en date du 15 septembre 2015, concernant un projet de recherche intitulé : « Traitement de la morphologie flexionnelle verbale » (TRAMORFLE-Verbale).

A l'issue de la délibération et au regard des éléments que vous apportez dans votre courrier, le Comité a considéré que *cette étude n'entre pas dans le champ d'application de la Loi du 9 août 2004*, dans la mesure où il s'agit d'une étude observationnelle, non invasive.

Cet avis tient lieu d'avis éthique (Numéro IRB : 00009118).  
Pour information, voici le site : <http://ohrp.cit.nih.gov/search/irbsearch.aspx>

Recevez, Monsieur, nos salutations les meilleures.

  
 Pour le CPP SUD-EST-II  
 Le Présidente - Docteur Catherine CORNU

Membres ayant participé à la séance :

BERTHOD Christelle (Médecin Généraliste) - BIENVENU Jacques (Recherche Biomédicale) - CHAMBOST Véronique (Pharmacienne) - CORNU Catherine (Recherche Biomédicale - méthodologie) - ERPELDINGER Sylvie (Recherche Biomédicale) - GUEUGNON Marine (Représentant Association Malades et Usagers) - MARCHAND Janine (Représentant Association Malades et Usagers) - NAGEOTTE Alain (Pharmacien) - NGUYEN Kim An (Recherche Biomédicale) - PAULIGNAN Yves (Recherche Biomédicale) - PHILIPPE-JANON (Domaine Social) - ROUSSET Guillaume (Domaine Juridique) -- SANN Léon (Domaine éthique).





# Appendix B



Rhône-Alpes Région



**INSTITUT DE SCIENCES COGNITIVES  
LABORATOIRE SUR LE LANGAGE, LE CERVEAU ET LA COGNITION**

67, boulevard Pinel  
69675 – Bron CEDEX

**CONSENTEMENT LOCUTEUR ETUDE 1 / EXPERIENCE 1**

*Je soussigné(e) :*

Nom : _____	Prénom : _____	Sujet : _____	Liste : _____
Age : _____	Nationalité : _____	Ordre : _____	
Langue maternelle : _____		Langues étrangères/temps : _____	
Sexe : M	F	Main : D	G

*accepte de participer à un test pour le Laboratoire sur le Langage, le Cerveau et la Cognition (L2C2) CNRS UMR5304 à l'Institut de Sciences Cognitives (ISC), 67 bd Pinel, Bron, dans le cadre du projet "Architecture lexicale verbale" réalisé par le Doctorant **Gustavo Lopez ESTIVALET** et sa Directrice de thèse **Dr. Fanny MEUNIER**. Cette expérience a reçu l'avis positif du **Comité de Protection des Personnes Sud-Est II**, Bron, France, numéro **IRB: 00009118**.*

*J'ai choisi volontairement de participer à cette recherche. J'ai été informé(e) du fait que je peux me retirer en tout temps sans fournir de justifications et que je peux, le cas échéant, demander la destruction des données me concernant. Je conserve tous mes droits garantis par la loi.*

*Je donne mon accord pour que le laboratoire utilise les données recueillies dans le cadre de l'étude sachant que ces données seront traitées de façon anonyme. J'autorise l'utilisation de données à des fins scientifiques et la publication des résultats de la recherche, étant entendu que les données resteront anonymes et qu'aucune information ne sera donnée sur mon identité. Toutes les questions posées ont été traitées de manière satisfaisante.*

*Je confirme avoir reçu un exemplaire de ce document signé et daté.*

Fait à \_\_\_\_\_ le \_\_\_\_\_

\_\_\_\_\_  
SIGNATURE



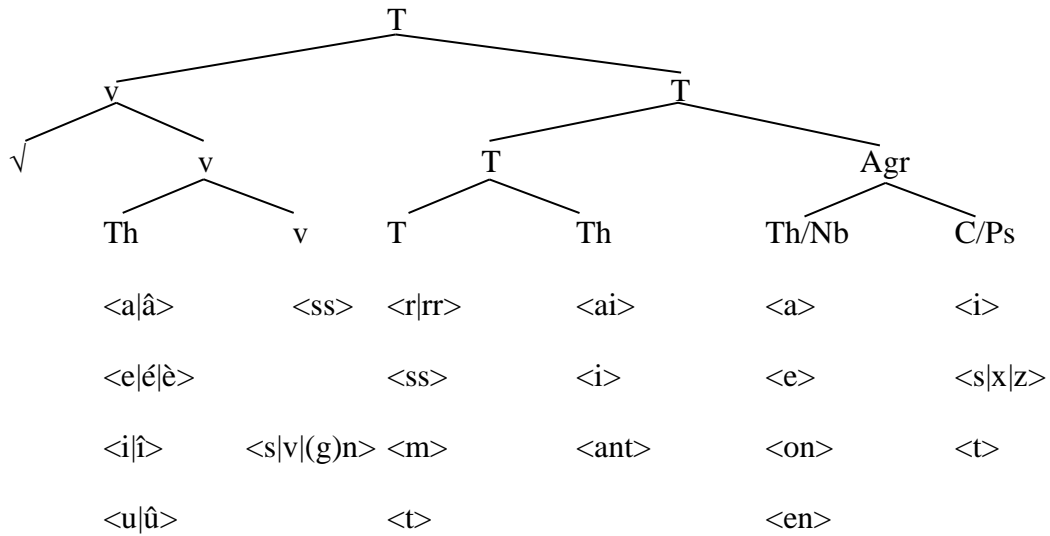
Université Claude Bernard



CENTRE NATIONAL  
DE LA RECHERCHE  
SCIENTIFIQUE



# Appendix C

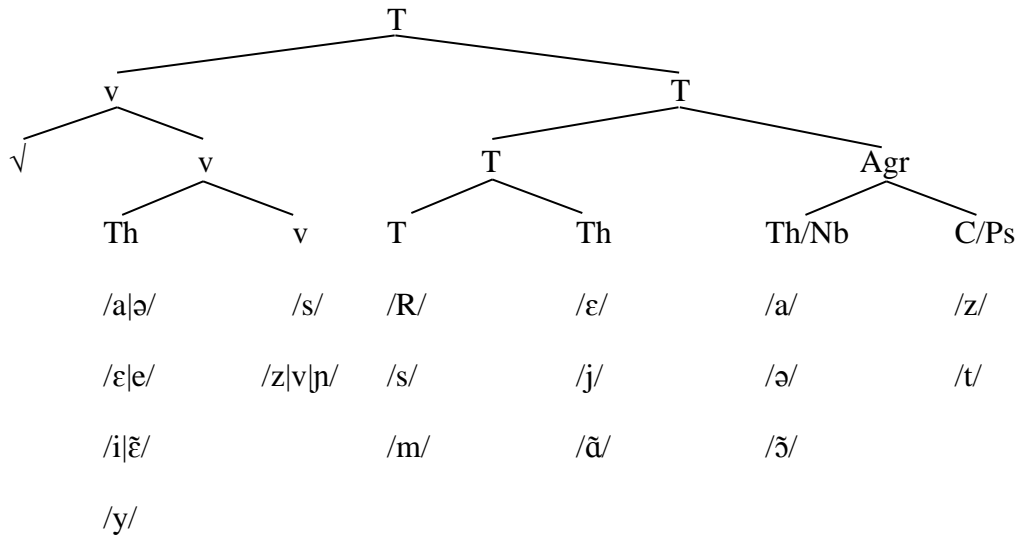


nb	Orthography	Phonology	Features	Node	Morpheme
1	<e>	/ə/	[sg]	T[Agr[Nb]]	[e] ↔ [sg]
2	<a>	/a/	[sg] [c1]	[Agr[Nb]] v[Th]	
3	<â>	/a/	[c1]	v[Th]	[a] ↔ [c1]
1	<e>	/ə/	[c1]	v[Th]	
4	<è>	/ɛ/	[c1, past, 3, pl]	v[Th]	
5	<é>	/e/	[c1, part.past]	[T]	
6	<i>	/j/	[1/2, pl]	[T]+[Agr[[Nb][Ps]]]	[i] ↔ [1/2, pl]
		/ɛ/	[1, sg]	[Agr[Ps]]	[i] ↔ [1, sg]
		/i/	[c2]	v[Th]	[i] ↔ [c2]
7	<î>	/i/	[c2]	v[Th]	
8	<u>	/y/	[c3]	v[Th]	[u] ↔ [c3]
9	<û>	/y/	[c3]	v[Th]	

10	<in>	/ɛ̃/	[c3]	v[[Th][v]]	[in] ↔ [c3]
11	<în>	/ɛ̃/	[c3]	v[[Th][v]]	
12	<s>	/z/	[c3]	v[[Th][v]]	[is] ↔ [c3]
13	<v>	/v/	[c3]	v[[Th][v]]	[iv] ↔ [c3]
14	<s>	/z/	[1/2, sg]	[Agr[[Nb][Ps]]]	[s]/[x] ↔ [1/2, sg]
15	<x>	/z/	[1/2, sg]	[Agr[[Nb][Ps]]]	
16	<ez>	/ez/	[2, pl]	[Agr[[Nb][Ps]]]	[ez] ↔ [2, pl]
17	<t>	/t/	[3]	[Agr[Ps]]	[t] ↔ [3]
18	<ons>	/ɔ̃z/	[1, pl]	[Agr[[Nb][Ps]]]	[ons] ↔ [1, pl]
19	<ent>	/ɑ̃t/	[3, pl]	[Agr[[Nb][Ps]]]	[ent] ↔ [3, pl]
20	<ont>	/ɔ̃t/	[3, pl]	[T]+[Agr[[Nb][Ps]]]	[ont] ↔ [3, pl]
21	<mes>	/mɛz/	[past, 1, pl]	[T]+[Agr[[Nb][Ps]]]	[mes] ↔ [past, 1, pl]
22	<tes>	/tɛz /	[past, 2, pl]	[T]+[Agr[[Nb][Ps]]]	[tes] ↔ [past, 2, pl]
23	<ai>	/ɛ/	[past]	[T]	[ai] ↔ [past]
24	<ss>	/s/	[c2]	V[[Th][v]]	[ss] ↔ [c2]
			[subj.past]	[T]	[ss] ↔ [subj.past]
25	<r>	/R/	[past, 3, pl]	[T[Agr]]	[r] ↔ [past, 3, pl]
		/R/	[inf]	[T]	[r] ↔ [inf]
		/R/	[fut]	[T]	[r] ↔ [fut]
26	<rr>	/R/	[fut]	[T]	
27	<ant>	/ɑ̃t/	[part.pres]	[T]	[ant] ↔ [part.pres]

Table 10 - Orthographic Vocabulary Items from the French inflectional system.

# Appendix D



nb	Phonology	Orthography	Features	Node	Morpheme
1	/ə/	<e>	[sg]	T[Agr[Nb]]	[e] ↔ [sg]
2	/a/	<a> <â>	[c1] [c1]	v[Th] v[Th]	
1	/ə/	<e>	[c1]	v[Th]	[a] ↔ [c1]
3	/ε/	<è>	[c1, past, 3, pl]	v[Th]	
4	/e/	<é> <e>+<r> <ez>	[c1, part.past] [c1]+[inf] [2, pl]	[T] [T[v[Th][T]]] [Agr[[Nb][Ps]]]	[a]+[r] ↔ [c1]+[inf] [ez] ↔ [2, pl]
5	/i/	<i> <î>	[c2] [c2]	v[Th] v[Th]	[i] ↔ [c2]
6	/y/	<u> <û>	[c3] [c3]	v[Th] v[Th]	[u] ↔ [c3]

7	/ɛ̃/	<in>	[c3]	v[[Th][v]]	[in] ↔ [c3]
		<in>	[c3]	v[[Th][v]]	
8	/ãt/	<ant>	[part.pres]	[T]	[ant] ↔ [part.pres]
		<ent>	[3, pl]	[Agr[[Nb][Ps]]]	[ent] ↔ [3, pl]
9	/õz/	<ons>	[1, pl]	[Agr[[Nb][Ps]]]	[ons] ↔ [1, pl]
10	/õt/	<ont>	[3, pl]	[Agr[[Nb][Ps]]]	[ont] ↔ [3, pl]
3	/ɛ/	<ai>	[past]	[T]	[ai] ↔ [past]
		<a>+<i>	[sg]+[1, sg]	[Agr[[Nb][Ps]]]	[a]+[i] ↔ [sg]+[1, sg]
11	/j/	<i>	[1/2, pl]	[T]+[Agr[[Nb][Ps]]]	[i] ↔ [1/2, pl]
12	/z/	<s>	[1/2, sg]	Agr[[nb][ps]]	[s]/[x] ↔ [1/2, sg]
		<x>	[1/2, sg]	Agr[[nb][ps]]	
		<s>	[c3]	v[[Th][v]]	[s] ↔ [c3]
13	/t/	<t>	[3]	[Agr[Ps]]	[t] ↔ [3]
14	/tez/	<tes>	[past, 2, pl]	[T[Agr[[Nb][Ps]]]]	[tes] ↔ [past, 2, pl]
15	/mez /	<mes>	[past, 1, pl]	[T[Agr[[Nb][Ps]]]]	[mes] ↔ [past, 1, pl]
16	/s/	<ss>	[c2]	[v[v]]	[ss] ↔ [c2]
		<ss>	[subj.past]	[T]	[ss] ↔ [subj.past]
17	/R/	<r>	[fut]	[T]	[r] ↔ [fut]
		<rr>	[fut]	[T]	[r] ↔ [inf]
		<r>	[inf]	[T]	
		<r>	[past, 3, pl]	[T[Agr]]	[r] ↔ [past, 3, pl]

Table 11 – Phonological Vocabulary Items from the French inflectional system.