Neural Correlates of Morphology Computation and Representation

Abstract

In this chapter, we critically review experiments on morphological processing focusing on compounds, derived and inflected words. Two main types of experiments are presented, those with single word or priming paradigms and those involving sentence processing, while focusing on morphological properties of words. We present as much cross-linguistic data as possible, in order to extract commonalities in morphological processing found across languages. Furthermore, studies on second-language learners, and occasionally early bilinguals, as well as child language development are presented, as they provide interesting data on differences and changes in brain behavior relating to morphological processing. Following this we discuss domains of further research while highlighting issues in data interpretation for present and future studies, in the hopes that readers will be encouraged to develop innovative research paradigms for the study of morphological processing.

Key words: Lexical access, Morphology, Compounding, Derivation, Inflection, Sentence processing, Child language, Second-language learning, Bilingualism

Phaedra Royle, Ph.D.

Université de Montréal, CRBLM, BRAMS, phaedra.royle@umontreal.ca

Karsten Steinhauer, Ph.D.

McGill University, CRBLM, karsten.steinhauer@mcgill.ca

1. Introduction

Since the 1980s ERPs have been used to study neurocognitive processes involved in lexical access. In this chapter we focus specifically on a component of lexical and syntactic processing called morphology. Linguistic morphology (from *morph*- 'form' in Greek) focuses on word structure. Morphemes are building blocks for words and phrases, and are usually defined as the "smallest meaningful units" in language. These are used to create new words but also to understand and process information in the incoming speech stream. For example, the word *undecomposable* is built of four morphemes: the stem *compose* (from the Latin morphemes, *com-ponere* 'together-put'), two prefixes *un*- and *de-,* and the suffix -*able*, all of which are derivational. Derivational prefixes and suffixes create new words from stem bases and may change syntactic category: *compose* is a verb while *composable* is an adjective. In contrast to derivation, compounding concatenates two stems to create new words, usually inheriting the head's[1] syntactic category (e.g., *blackbird*). Thirdly, inflectional morphemes, such as plural -*s* and past tense -*ed*, add mostly grammatical information to stems or derived forms. Thus, inflection does not create new words or change the word class (noun, verb, etc.). Unlike most Indo-European languages, Semitic languages such as Arabic use root-and-pattern processes to create words where roots, such as √ktb, are interleaved with vowels to create words such as *kitab* 'book'. Different languages instantiate morphological processes to larger or lesser extents, and some derivational processes such as reduplication, are not discussed here because they have not yet been studied (but see (1) for preliminary data on Malagasy reduplication).[2] Some languages like Mandarin only productively use compounding, while others–such as Turkish–rely heavily on

[1] Headedness (e.g., right vs. left) differs across languages.
[2] Reduplications, as its name implies, involves full–or partial–reduplication of a root or word stem. It is used for both derivation and inflection. For example, in Malagasy *halo* 'mix' is reduplicated to create *halohalo* 'mixed desert'.

inflectional and derivational morphology. Almost all Turkish words have multi-morphemic structures consisting of at least two morphemes. Morphological theory is a vast domain of research in linguistics and psychology, and many theories of morphology and morphological processing have been put forward (see also (2, 3)). Bloomfield proposed that all aspects of language that could not be derived by a rule (e.g., word stems) should be "in the lexicon" while other predictable aspects (e.g., derivation and inflection) should be rule-generated (4). In *Remarks on Nominalization* (5), Chomsky proposed that a distinction should be made between derivation (a lexical process) and inflection (a syntactic process). This approach–a distinction between lexical and syntactic processes–has also been pursued in psycho and neuro-linguistics, even within inflectional morphology. For example, a distinction between regular (combinatorial) inflection (e.g., *walk* + *-ed* → *walked*) and irregular (lexicalized) inflection (*teach* → *taught,* not **teached*) has been proposed This assumes that all irregular forms are non-derivable from rules and must thus be lexicalized (see, e.g., (6)). In contrast, regular forms such as *walked* are typically decomposed into their constituent morphemes but could exceptionally be stored as a lexical entries if they are used very frequently. This idea of two access routes to the same word is reminiscent of some models proposed at the end of the last century that advocated for "dual-access routes" to the lexicon: one decompositional and one "whole-word". Depending on the model, distinctions between parallel competitive processing and exclusive types of access can be made, where one type or sub-type of morphology is exclusively processed using one of the available routes (see, e.g., (7–15)).[3] Within these approaches, research focused on which factors would promote, or demote, morphological versus whole-word access. More recently, Matushansky and Marantz's *Distributed Morphology* proposed that all word-formation

[3] Triple route models involving whole-word, decomposition and analogy are not addressed in neuropsychology (201, 202).

processes are syntactically generated, irrespective of whether they are regular or irregular, or involve derivation or inflection (16). Their approach is interested in abstract *rule* representation and implementation rather than morphological *phonological* realisation. We will see that some neurocognitive studies of morphology directly address this distinction. Finally, on the other end of the spectrum, there are theories of morphology that ultimately reject morphology as a distinct linguistic or psycholinguistic construct. For example Bybee proposed that "Morphological properties of words, paradigms and morphological patterns once described as rules emerge from associations made among related words in lexical representations" (17). This "emergentist" approach has been supported by others who propose that what appear to be morphological "rules" are in fact the result of recurring semantic and phonological patterns (see also (18–21)).

In this chapter we will present ERP and MEG research investigating morphological processing using visual or auditory, word or sentence comprehension, and occasionally production. For fMRI research on morphology, we refer interested readers to a recent review (22). One might wonder why morphological structure and processing are of interest to the neurosciences. As just mentioned, there is a big debate about the status of morphology in the brain, and neuroscientific research has addressed a number of issues pertaining to this. Research questions regarding morphology addressed through ERP and MEG research include the following: Are morphemes represented in the brain? Does the brain always decompose words into their constituent morphemes? Are there differences in parsing between different morpheme types? And how does morpheme processing differ across languages?

A majority of ERP studies on morphological processing have been run in Indo-European languages such as English and French, which have relatively impoverished morphological systems, or Spanish, German and Greek with richer morphologies. Nevertheless, numerous EEG and MEG studies have focused on Finnish, a non-Indo-European and morphologically abundant language. As we shall see, recent work has been extended to other language families, allowing us to develop a better understanding of morphological processing from a cross-linguistic perspective. We will present results from single-word processing studies involving multimorphemic words (compounds, derived and inflected words) and studies of words in sentences (with the majority involving inflected words). Furthermore, we dedicate Section 4 to studies on multilinguals and children, as they are important for our understanding of how language learners converge on functional language processing. These are followed by short discussions of results, shortcomings, challenges, and unresolved issues, while the chapter ends with a global discussion and suggestions for further neurophysiological research of morphology.

Methods used for the investigation of morphological processing with ERP and MEG are typically similar to those used in the psycholinguistic literature on lexical access (see also Chapters 5–7). The most prevalent ERP paradigms combine visual target-word presentation with lexical decision tasks, sometimes involving priming. This method is useful for morphological processing research as it can induce ERP component modulations that vary in timing based on the type of relationship between prime and target (23). Other approaches use sentence contexts (typically with rapid serial word-by-word visual presentation, or *RSVP*, usually 300–500 ms per word) (24–26). This is more often the case for inflection morphology, such as subject-verb number agreement. Furthermore, as sentence contexts can be used to create agreement violations–e.g., between subject and verb, e.g., *As a turtle grows its shell *grow too* (25)–violation paradigms with sentences are quite common. Finally, although most reviewed studies focus on comprehension, a few have also studied word production (e.g., 27, 28). This imbalance is partly due to the fact that this approach demands mouth and tongue articulation, which can create movement artefacts and readiness components that can complicate data analyses (see e.g., 28, 29). Unless specified, all studies reported use visual word presentation.

1.1. ERP and MEG Components for the Study of Morphological Processing

The N400 is the most commonly studied ERP component associated with morphological processing, but other negativities (the N250 and the LAN, or *left anterior negativity*) are also used as indices of lexical form and grammatical features linked to word structure or morphosyntactic processing. The N400 is particularly sensitive to word- and sentence-level properties of morpho-lexical and lexical-semantic processing and sub-lexical properties such as frequency, concreteness, syntactic category, sensicality within the sentence, and discourse context (24, 30, 31). In MEG, the M350 magnetic field reflects similar effects (32–34). Left anterior negativities (LANs, more reliable in auditory than reading studies), are observed in cases of overregularization (e.g., *singed* for *sang*), and inflection or agreement errors. Thus, LANs have been interpreted by some as reflections of rule-based processes while N400s have been linked to lexical-semantic retrieval (see Chapters 15, 18 for further discussion). Other components that will be mentioned in this chapter are the *mismatch negativity* (MMN), the N100, the P200, the P3b and the P600 (we refer to Chapters 12, 14–18 for more details on these components). There is no counterpart for the P600 in MEG.

2. The Existence of Morphology

Although one might thing that linguists and psycholinguists mostly agree that morphology is a component of language, its status in linguistics, psychology, and the neurosciences is less than settled. Thus, one major question in the neuroscience of language is whether words are processed as indivisible “chunks” or rather decomposed into morphemes during recognition (or production). Four main approaches have been pursued. The first is to compare compounds, derived or inflected words with underived or uninflected forms, in order to probe differences in activation for multimorphemic and monomorphemic words. All else being equal, finding differences between these types would indicate sensitivity to word structure and thus morphological units. Furthermore, evidence of early effects is taken to support automatic or irrepressible morphological processing during word recognition. The second approach is to study constraints on word formation, that is to check whether speakers are sensitive to word-structure rules. This establishes what morphological rules are active when we process real and novel derived words. For example, English speakers know that **re-white* is not a possible word, because *re-* is usually prefixed onto verb stems. A third method is to compare morphological, orthographic (or phonological) and semantic priming effects on target recognition, in order to differentiate these from each other, and establish whether morphological priming goes beyond semantics and orthography/phonology, signalling its special status. Fourth, many studies question whether morphological decomposition is obligatory or optional. To address this, factors known to promote or demote morphological processing are manipulated. Those identified in our review include word and stem frequency, morpheme productivity, semantic transparency, inflection regularity, and inflection default status. We present the concept of frequency here, as many different studies reported in this chapter integrate this factor into their designs. Frequency manipulations–of stem or of morphological process–are based on the following premise: If complex words with more frequent stems are processed more efficiently than those with less frequent ones, one can postulate that this reflects stem access. Stem frequency effects affect whole-word recognition in behavioural tasks, which implies that derived words and compounds can be decomposed (e.g., 35). Further, when more frequent (i.e., productive) *affixes* are better processed than less frequent ones, this is taken to reflect online morphological decomposition.

2.1. Comparing Word Structures

Studies comparing monomorphemic and multimorphemic words have generally focused on derivation. A Finnish investigation of spoken-word judgements with both EEG and MEG using derived (e.g., *karva-ton* ‘hairless’) and monomorphemic words (e.g., *morsian* ‘bride’, see also Section 2.3 for other comparisons) found that ERPs for derived forms showed early negativities (80–120 ms), after either the word’s uniqueness point[4] or suffix onset, as compared to monomorphemic forms (36). MEG source-modeling revealed that derived words eliciting stronger source amplitudes than monomorphemic ones in the right superior temporal lobe ∼100 ms after stem offset, suggesting that stem and suffix morphemes are initially activated along with whole-word representations during auditory processing. Investigating the impact of frequency on morphological processing, a Finnish study measuring mismatch negativities (MMNs) to the presence versus absence of derivations found that derived words (e.g., *laula-ja* ‘singer’) showed larger MMNs 100–150 ms after suffix onset than pseudo-derivations (e.g., *raula-ja*), and that frequent forms (*laula-ja*) elicited larger MMNs than less frequent ones (e.g., *kosta-ja* ‘avenger’) (37). These early effects modulated by word frequency provide evidence for first-pass morphological processing. However, derived words were always deviant while standards were always monomorphemic real words (e.g., *laula* ‘sing’) (see Section 2.6.1 for why this is problematic). Converging evidence comes from two studies. The first on French lexical decision where larger N400s are found for non-suffixed words (e.g., *fortune* ‘fortune’ = containing the pseudo-stem *fort* ‘strong’ + *une*) than to truly suffixed (e.g., *poch-ette* ‘little pocket’ = *poche* ‘pocket’ + diminutive suffix *-ette*) and pseudo-suffixed words (e.g., *mouette* ‘seagull’ = with the pseudo-stem *mou* ‘soft’ + and pseudo-suffix *-ette*), but no differences between truly and pseudo-suffixed nouns, indicating automatic parsing of all potential stems and difficulties (i.e., larger

[4] The point where the word has no other lexical competitors, here used for monomorphemes.

N400s) when the result of this parse is “illegal” (38). Interestingly, N400 onset latencies occurred early in truly-suffixed conditions (~300 ms), later in pseudo-suffixed conditions, and latest in non-suffixed ones (both after 400 ms). These suggest that morphological information is processed rapidly in multi-morphemic words. The second study uses both MEG and ERP with a passive MMN listening task (39). Suffixed and pseudo-suffixed nouns and verbs (e.g., *baker*, and *beaker*) were compared to unaffixed forms (e.g., *bacon, beacon* containing pseudo-stems /beyk/ or /bik/, with -*on,* a non-valid suffix), and pseudo-derived words with novel stems (e.g., *boker, bocon*). Onset timing was set at stem, pseudo stem or novel stem offsets (/k/ in these examples). Early left-lateralized MMNs at 160–170 ms were found only for real and pseudo-derivation (e.g., *baker* and *boker*), and truly suffixed words also showed larger MEG effects than non-words (e.g., *baker* > *boker*) at 150–185 ms. In even later time-windows (240–280 ms), opaque words showed larger MEG effects in the right hemisphere than pseudo words (e.g., *beaker* < *baker*), reflected in ERPs as left-posterior negativities for transparent words, and central positivities for opaque ones. Non-words and pseudo-complex forms showed no significant differences. These data provide support for early segmentation of all possible suffixes, with sensitivity to lexicality, as well as real versus pseudo-derivation in early N400 time-windows.

A stem’s status as being more or less productive might also impact how we process it. This has been investigated with different root types: free roots that occur as underived words in English (e.g., *tax* in *taxable*), bound stems found only in derived words (e.g., **toler* in *tolerable*) and unique roots, that appear in only one derived form (e.g.,**vulner* in *vulnerable*). Focusing on early MEG responses (100–200 ms post-stimulus), (40) found that the M170–the MEG counterpart to N170s elicited by visual stimuli in ERPs–was sensitive to morphological properties such as affix frequency and the conditional probability of encountering each word given its stem (its *transition probability*). This suggests parsing of all possible roots, even those that never occur outside their derived form. Another study (41) confirms that words with "no valid rule" for decomposition (e.g., *wint-er,* where *wint*, a pseudo-stem is pseudo-suffixed), elicit weaker M170 amplitudes than words containing bound stems (e.g., *valuable*) and free ones (e.g., *agreeable*). No-valid-rule items showed lower activation than expected given their transition probability, suggesting that we use morphosyntactic rules to avoid incorrectly parsing words into affixes and non-existent stems.

A few studies have compared compounds to monomorphemic words. A main issue in compounding research is whether, when we access compounds, we also individually access their constituents (e.g., *blackbird* = *black* + *bird*). Earlier M350s are found for compounds (*teacup*, mean latency 333 ms) and pseudo-compounds (*crowskep*, 340 ms) versus monomorphemic words of equal length (*crescent*, 361 ms) (42). A follow-up ERP study (43) finds early and stronger N400 reductions (275–400 ms) for real compounds and intermediate N400s for novel ones. Results on novel compounds suggest effortful processing, but could also be linked to unfamiliarity. Similarly, in Italian, non-compounds with pseudo-morphemes (e.g., pseudo-morpheme *cocco*, 'coconut' in *coccodrillo*, 'crocodile') have also been found to elicit larger N400s than real morphemes (e.g., *capo* 'head' in *capobanda*, 'band leader', 44) suggesting parsing of all possible morphemes and difficult integration when they are not real. In contrast, one study (45) does not find evidence for obligatory compound decomposition when manipulating spelling errors in a sentence reading task. However, participants were at 40% post-hoc accuracy recognizing words used during the EEG recording. It thus remains unclear whether this paradigm in fact tapped into morphological processing.

2.1.1. Constraints on Derivation

An interesting way to investigate morphological processing is to study legal and illegal morphological combinations by creating novel word forms to study sensitivity to morphological rules and constraints. Affixes have constraints on how and when they can be adjoined to stems, for example *un-* must be prefixed on adjectives but not verbs. Further, these constraints can be at the word-category level (e.g., **reblue* combines a verbal prefix with an adjective), or argument structure level (e.g., **relaugh* combines *re-* with a non-transitive verb, which is also illegal). ERP studies find that listeners/readers are sensitive to these constraints. Category errors elicit larger N400s (followed by P600s) than real derived or novel legal forms in Finnish (46) and in German words presented RSVP (47), as well as frontal negativities in Finnish single-word presentation (48). However, in two of the studies (47, 48) structurally illegal novel forms (**einstimmreich,* 'unanimously' from 'unanimous+rich' in German[6]) do not elicit significantly larger N400s than novel but interpretable forms (*einstimmlich,* novel 'unanimously'), making these effects difficult to distinguish from frequency effects on morphological parsing. Category errors elicit significant MEG differences between illegal and legal novel forms, illegal forms eliciting strongest effects in the M350 time window (although late at 400–575 ms) (49).

More interesting however are MEG studies comparing novel items with category violations (e.g., Greek **lehano-tos* 'cabbage-able', *-tos* can only affix onto transitive verbs), to novel items with argument structure violations (**tremi-tos* 'tremble-able', *tremi* is intransitive) and real suffixed words (*sevas-tos* 'respectable') (50). These elicit early (M170) form-based effects of morphological decomposition (for real and novel words), but, importantly, stem-suffix category violation effects from 200–300 ms, and argument-structure effects at later time-windows (300–500 ms), which are argued to be linked to semantic re-composition. Similar results are found in

[6] *-reich* can only combine with noun stems, e.g., *farbereich* 'colour+rich = 'colourful'.

English, with stronger category than argument structure violation effects in early time-windows (200–300 ms), as well as later ones[7] (325–440 ms) (51). Later effects, argued to index re-composition, are less robust in English than in Greek. This could be linked to affix homonymy in English (i.e., *out*- and *un*- have homophonous morphemes that affix to other bases) which makes illegal word categorization more difficult. Furthermore, Greek is morphologically rich and productive, and the data seems to suggest that Greek speakers may be faster or more reliable than anglophones at picking up on morphological information.

2.1.2. Constraints on Inflection

Inflection encompasses numerous phenomena such as tense, subject-verb agreement, intra-nominal agreement within noun phrases (e.g., gender, number and case) as well as long-distance agreement in phrases or sentences (involving, for example, pronouns and other function words). Studies of inflection regularity are numerous at least partly because early psycholinguistic models posited distinct processing pathways for regularly and irregularly inflected forms e.g., *sin – sinned* vs. *go – went* (see e.g., 52).

As with derivation, a few studies have assessed sensitivity to inflectional structural legality using novel word forms. A Finnish ERP study (53) found that real suffixed and monomorphemic words elicited smaller N400s than pseudowords containing real suffixes (**värö+ssä* = pseudostem **värö* + inessive case[8] -*ssä*), pseudowords containing real stems (e.g., **onni+tla* = *onni* 'happiness'+ pseudosuffix -*tla*), monomorphemic pseudowords (e.g., *kamsteri*), and illegal pseudowords combining both real stems and suffixes (e.g., **lammasen, lamma* 'sheep' + -*en* genitive suffix, rather than *lampaan* 'of-the-sheep'). However, this effect was reversed in low-

[7] With the exception of *re*- prefixed words which show the opposite pattern.
[8] A locative case in Finnish.

frequency items, suggesting that all else being equal, it is easier to process frequent multimorphemic than monomorphemic words in Finnish, but at lower frequencies this processing advantage is lost. Results also point to sensitivity to real vs. pseudo stem status: Enhanced N400 effects were found for pseudowords containing real stems, but, importantly, not pseudo-inflected forms containing pseudo-stems.

As many word-processing studies are visual, a relevant question is whether morphological effects are modality specific. This has been investigated in Finnish (54) by presenting case-inflected words and pseudowords (both novel and pseudo-inflected) in auditory and visual modalities. Pseudowords elicited larger N400s than other types, and this effect was more pronounced in the visual modality. N400s effects for real inflected words were earlier by 200 ms in the visual task, possibly reflecting immediate information availability, but also averaging effects, as auditory presentation results in subtle timing jitter between stem-based information availability in different targets. Finally, ERP responses to "complex" pseudowords did not differ from monomorphemic pseudowords in either modality. These two last studies thus suggest together that case-inflection processing requires real-word stems to occur.

2.2. Priming Studies for Morphology

Priming studies for inflected and derived words have investigated morphology's special status as compared to orthographic/phonological (i.e., formal) and semantic priming. The assumption is that if morphology is a combination of semantic and orthographic or phonological overlap, and is not represented distinctly in the brain/lexicon, then it should in fact reflect the summation of semantic and formal priming effects. A Spanish priming study (55) used long stimulus-onset asynchronies (300 ms, time enough for semantic priming effects to emerge), to compare morphologically related words with gender-marked suffixes (*hij-o* – *hij-a*, 'son – daughter'), stem homographs with *no* morphological relationship (*foc-o – foc-a,* ‘floodlight – seal’), and unrelated pairs (*pav-o – met-a* ‘turkey – goal’). Morphological priming reduced early and late N400s, while stem homographs attenuated early N250s[9] (250–350 ms) and *increased* N400s (450–650 ms). Pairs with orthographic overlap (*rasa – rana,* ‘flat – frog’) did not modulate ERPs, while synonym pairs (*cirri-o – vel-a* ‘candle.m – candle.f’) induced both very early and late negativity attenuations (250–350 ms and 450–650 ms) which were significantly weaker than morphological priming effects in early time-windows (250–350 and 350–450 ms), but not later ones (450–650 ms). These data show strong effects for across-the-board morphological priming, early effects for shared orthography and morphology, and only weak effects for semantic priming. However, conditions were presented in different experiments not directly compared across them, and different targets were used in all cases. A more recent French study did directly compare priming conditions, contrasting morphological (e.g., *cass-ait – casse* ‘broke – break’), semantic (e.g., *brise – casse* ‘break – break’), and orthographic priming (e.g., *cassis – casse* ‘blackcurrent – break’) to the same target, presented with short 50 ms interstimulus intervals (56). In this case, semantic priming did not modulate ERPs, orthographic primes showed weak N250 modulations, and morphological priming induced strong and longer lasting N250-N400 reductions (Figure 1), confirming the special status of morphological priming over and above orthographic priming, and to the exclusion of semantic priming.

Figure 1 here

[9] The N250 is occasionally labeled the early N400. It can index formal processing (203, 204).

However, although care can be taken to equate semantic overlap conditions with morphological ones as in the previous example, this is difficult to do in Indo-European languages. Furthermore, the two studies presented above (55, 56) provide evidence for stem priming, but say nothing about the active use of inflection in word processing. A recent study (57) takes advantage Hebrew's properties by priming inflection patterns rather than stems. To do this, the verb root was changed but the inflection frame remained stable (e.g., ***hi**xsh**i**v* 'considered' primed ***hi**zk**i**r* 'reminded', bold phonemes are the inflection frame while un-bolded consonants are the root, here √xshv for 'considered'). This condition was first compared to traditional morphological root priming (e.g., ***ni**zkh**a**r* – ***hi**zk**i**r* 'remembered – reminded'), and unrelated pairs (e.g., *x**a**l**a**f* – ***hi**zk**i**r* 'passed – reminded'). Importantly, vowel information, which is not usually spelled in Hebrew, was presented. In a second experiment vowels were removed, and an additional priming condition with the target vowel pattern from a different lexical category was used (e.g., TSLL for *ts**a**l**a**l* 'dove'[10] vs. BSR for *b**a**s**a**r* 'meat' priming RXTS for *r**a**x**a**ts* 'washed'). MEG results in the first experiment showed early (227–247 ms) and later (386–460 ms) modulations for shared root priming, as well as late effects (434–460 ms) for shared inflection templates. In the second experiment, similar underlying vowel patterns from shared templates–but not from different templates–showed priming in both early (177–219 ms) and late time-windows (300–373 ms), while effects for shared roots were not observed. Overall, what these studies highlight is that in Hebrew, inflection patterns will prime target recognition independently of vowel cues, but that root priming–contrary to what has been found in other languages–is only facilitated when vowel cues are also provided. This last effect, although puzzling, is not inconsistent with other psycholinguistic studies in Hebrew. In particular it has

[10] The past tense of 'dive'.

been argued that a shared root does not necessarily result in priming in Hebrew because the root can be realized as different lexical categories (verb, noun, adjective etc.).

One study provides evidence against a special status for morphology, using unmasked derivation-priming with ERPs, of semantic (e.g., *vault –arch*), morphological (*archway – arch*), orthographic (*archer – arch*),[11] and control (*frog – arch*) conditions to the same target. N250s were reduced by morphological and orthographic overlap, while N400s were reduced by both semantic and morphological overlap, providing evidence that morphological priming can be accounted for by cumulative orthographic and semantic effects (58). However, long stimulus onset asynchronies (600–750 ms) might have promoted strategic semantic priming effects that are effectively absent in masked-priming paradigms, but also unmasked priming, depending on prime presentation time or task (56). A case in point comes from a French experiment with unmasked primed lexical decision, and 250 ms onset asynchronies, comparing morphological (*lavage – laver* 'washing – wash'), semantic (*linge – laver* 'clothes – wash'), and orthographic conditions (*lavande – laver* 'lavender – wash') (59). Significant early morphological effects were found (100–250 ms, reduced P200s), as well as significantly stronger N400 amplitude reductions in morphological priming (250–650 ms) versus semantic and orthographic conditions. Orthographic priming *increased* N400s in comparison to unrelated priming. Similarly, a French MEG study (60) with unmasked-priming for derived (*ourson – ours* 'bear cub–bear'), orthographic (*oursin – ours* 'sea urchin–bear'), and semantic conditions(*peluche – ours* 'stuffed toy–bear') finds reduced M250s specific to morphological priming, but also MEG reductions in the 585–650 ms time-window in morphological versus orthographic and semantic conditions.

[11] Note that *archer* and *arch are* in fact morphologically related. The relation is semantically opaque in English. Stimuli lists were not provided.

2.3. Dissociations Between Morphology Types

A number of studies have focused on distinctions between inflection and derivation. This approach allows us to disentangle processes that are putatively more lexical (derivation) from those that should be more grammatical (inflection). Because derivation often changes word-category and creates new lexical entries, while inflection does not, it could be that underlying cognitive systems used to process these different information types are distinct.

The study on derivation presented above (39) also contrasted derivation and inflection using suffixed nouns and verbs with derived (e.g., *baker, beaker*), inflected (e.g., *bakes, beaks*), and unaffixed forms (e.g., *bacon, beacon*), as well as non-words (e.g., *bokes, boker, bocon*). MMNs were larger for derived versus inflected words, both effects being left-lateralized. Because the effect was early (on MMNs) it was argued to reflect automatic parsing. A follow up MEG study by the same group (61) used single-word recognition of transparently inflected and derived forms (e.g., *blinked*, *farmer*), pseudo-suffixed (e.g., novel *ashed,* or underived *corner*), nonce words (e.g., *bected*) and stem (or pseudo-stem) processing (e.g., *blink, corn, ash,* etc.). Differences in activation were found between inflected and derived forms: while derivation activated the frontal mid temporal gyrus more strongly than inflection (between 330–340 ms), inflected words elicited stronger activation than derived ones in the posterior mid temporal gyrus (300–320 ms), BA 44 (320–370 ms), and BA45 (350–370 ms), which, according to (61), argues for distinct underlying cognitive processes in inflection and derivation processing, despite the fact that activation for both types were found in all regions, weakening the argument for distinct underlying mechanisms.

A Finnish study (62) compared listening to derived (e.g., *karva-ton* ‘hairless’) and inflected words (e.g., *talo-ssa* ‘in-a-house’, a locative form) versus monomorphemes (e.g., *morsian* ‘bridle’) using non-attended in comparison to attended (judgement task) results from (36) above in Section 2.1. They observed that suffixed words elicited early ERP and MEG responses (~100 ms) that did not differ according to task, with larger effects for derived as compared to inflected and monomorphemic words. In later time-windows (~200 ms), differences between types were only observed in the attended task where inflected words elicited larger posterior positivities in ERPs and bilateral MEG components not found for other word types. This is argued to provide evidence for automatic task-independent first-pass spoken-word morphological processing, but also attentional effects in later morphological processing stages, more specifically on inflection processing. Very early effects in this experiment are not surprising, as analyses were time-locked to suffix onset,[12] by which point stems had already potentially been recognised.

2.4. Productivity Effects in Morphology

Morphological productivity can impact our ability to process morphological structure. For example, words ending in -ity (*serenity*) are created with a less productive suffix than words derived in -able (*enviable*) and might thus be more difficult to parse into their constituents, and lead to whole-word access (or "chunking"). If this is the case, words built upon less productive morphological rules might be lexicalized (i.e., processed as monomorphemes) or, if parsed as morphologically complex forms, might be more difficult to process, eliciting stronger effects. In addition, inflectional regularity and its interface with orthographic or phonological overlap has also been explored, since irregular forms tend to have less transparent orthographic or phonological overlap with stems. This is a valid line of inquiry, as regularity effects on morphological processing may emerge simply from phonological transparency or overlap effects, rather than from putative differences in morphological representation.

[12] Or uniqueness point in monomorphemic words.

2.4.1. Productivity Effects in Derivation

Derivational productivity has been found to affect lexical processing in adults and children (14, 63). As far as we know, only one study addressed this issue by manipulating derivational family size, a productivity measure. MEG evidence supports early derivational family entropy[13] effects in the left middle temporal (241–387 ms post-stimulus onset) and the left superior temporal lobes (242–326 ms), stages which are argued to correspond to stem lookup for derived words in English, while a later trend for whole word surface frequency effects (446–477 ms) in the left superior temporal lobes is interpreted as corresponding to a recombination stage (64).

2.4.2. Productivity in Inflection Versus Derivation

As we have seen, differences have been found between inflection and derivation in MEG and ERP data, but these could be attributed to affix productivity. Because, as we have seen, derivation is constrained by more than word category while inflection can often apply across the board within a word category, differences in productivity might be contributing to observed effects. An ERP study contrasting productivity in Dutch derivation and inflection using visual lexical decision, used items with productive and less productive derivational suffixes (e.g., *dreig-ing* 'menace' vs. *stoor-nis* 'disorder'), or regular inflection (which is productive, *gooiden* 'throw') versus irregular inflection (which is unproductive, *smolten* 'melt', see Section 2.5.3 for more on transparency in inflection) (65). These were presented within lists of novel non-decomposable nonwords (e.g., *schirsan*) or lists containing nonwords with possible suffixes (e.g., *duur-heid* 'expensive'), as well as monomorphemic real words (e.g., *soldaat* 'soldier'). Sustained negativities for suffixed words were larger for inflected versus derived forms across 200–700 ms time-windows. Larger negativities were also found specifically for irregular as compared to

---

[13] A measure derived from the lexical frequencies of a given stem's morphological family members (205).

regular forms in the 350–500 ms time-window. Finally, presentation contexts modulated results: when presented within lists of novel words with possible stems and suffixes, suffixed words elicited larger negativities in 350–700 ms time-windows, in addition to positivities (between 500–900 ms). Thus, inflection transparency appears to have more important neurocognitive consequences than derivation productivity in single-word processing, and in contexts promoting morphological processing strategies. In essence, low-transparency inflection appears to be more difficult to process than low-productivity derivation, highlighting potential explanations for distinctions between derivation and inflection processing.

2.5. Semantic Transparency Effects on Morphology

Words can have transparent or opaque semantic relationships with their constituent parts. For example, compounds vary on a continuum from semantically opaque, where meanings of the compound's two parts are not transparently related to the meaning of the whole (e.g., *choke cherry* is not 'a cherry that can choke'), to semantically transparent, where one can semantically parse it into its constituent meanings (e.g., *blueberry* is 'a berry that is blue'). The same can be said for derived words (e.g., compare transparent *monstress* from *monster* with opaque *mistress*, from *master*). Semantic transparency could be expected to impact word processing: in particular, if a complex word is opaque, we might not access its morphological constituents. Transparency often intersects with productivity, as less productive derivations tend to be less semantically or morpho-phonologically transparent, since many historically-derived words are synchronically opaque (14, 66–68). Evidence for morphological processing would come from differential effects for transparent versus opaque forms, the second type being more effortful and possibly processed by different cognitive mechanisms than the first.

2.5.1. Transparency and Compounding

A German compound study manipulated transparency using auditory presentation of transparent compounds (e.g., *Milchkanne* [MILK] + [CAN], 'milk pail'), and elicited increased frontal and posterior N400s on the head constituent (*Kanne*) as compared to opaque ones (*Schneebesen* [SNOW] [WHISK] 'egg beater') (69).[14] These results suggest that opaque compounds are not decomposed. However, another group contrasted compounds composed of words (W) and nonwords (N) in the auditory modality (e.g., WW: *Ameisenhaufen* 'anthill'; WN: *Maschinenbönf* 'machine-bönf'; NW: *Patoseschlot* 'patose+chimney'; and NN: *Kronubejosche* 'kronube+josche'), and found this same frontally prominent negativity on compounds' initial nonword constituents, as well as on second constituents when compounding resulted in a novel form (70). Second constituents also elicited classic N400 effects modulated by both first and second constituent word status: WN and NW compounds elicited larger N400 amplitudes than NN ones, suggesting lexical search and attempts to integrate these constituents into a word.

In order to evaluate whether opaque compounds can be decomposed as efficiently as transparent ones, a Dutch ERP study used compound-word priming for picture naming[15] with morphologically related transparent compound primes (e.g. *eksternest* 'magpie nest' → [MAGPIE] *ekster*), opaque compound primes (e.g. *eksteroog* 'magpie-eye' = 'corn' → [MAGPIE] *ekster*) and form-related primes (e.g. *jasmijn* 'jasmine' → [COAT] *jas*) (71). Morphologically transparent and opaque primes equally facilitated picture naming and reduced N400s, while form overlap did not. However, a subsequent MEG study did find transparency effects using constituent priming and word naming for transparent (e.g., *road – roadside*),opaque compounds (e.g., *butter – butterfly*), and form overlap (e.g., *broth – brothel*) (72) (see Figure 2). Naming onset latencies were shorter for all compounds versus non-compounds, while MEG

[14] Note, however, that *Schneebesen* has a less frequent but transparent meaning 'snow broom'.
[15] All items–prime words and targets pictures–were named.

activity was stronger only for transparent compounds (250–470 ms and 430–600 ms). Another lexical decision study (73) compared compounds with semantically transparent (T) or opaque (O) stems (e.g., TT: *bedroom*; TO: *cardshark*; OT: *chopstick*; OO: *deadline*). Both first- and second-constituent transparency uniquely predicted P100 amplitudes–the more opaque, the larger the P100–while second-component transparency predicted N400 amplitudes: TT and OT compounds were more negative. This suggests that semantic access at some level occurs as early as the P100 and persists through to the N400. These results were argued to contradict form-first morphological processing models (e.g., (40, 64)), which are not supposed to care about meaning. However, this experiment used only 10 items per condition, and these were repeated across the experiment, calling into question its representativity. P100 effects might have arisen from high item-predictability within lists.

Figure 2 here

Compound frequency and headedness properties have been sparsely studied in neurolinguistics. Stem frequency effects on ERP or MEG would imply that base morphemes are being activated during compound processing, while headedness effects indicate sensitivity to word-internal hierarchical structure. A study in Basque (75) manipulated compound constituent frequency (e.g., High-Low: *eskularru* 'glove', from *esku* 'hand' + *larru* 'skin') during RSVP. Compounds were presented at sentence onset to avoid contextual priming (e.g., *Bizkarzain* [bodyguards] *gutxi dauzkaten politikariak oso baikorrak dira* 'Politicians that have few bodyguards are very optimistic').[16] Stem-frequency effects varied according to their position in the compound. Early N200 modulations on the first stem were *larger* for frequent than less

[16] Within-sentence presentation was argued to be more ecological than single-word presentation, which is more likely to tap into post-lexical effects.

frequent ones. The opposite pattern was observed in the N400 time-window, where lower-frequency second stems increased right-lateralized negativities. These data are in line with behavioural data showing strong second-stem frequency effects on lexical access but more subtle ones for the first stem (or even inhibition, 58). However, a Mandarin Chinese study (76) found different facilitative or inhibitory whole-word and constituent-frequency effects on N250s and N400s. The first morpheme frequency was manipulated while maintaining the second one constant, resulting in compounds with high and low initial stem frequencies and high or low whole word frequencies (e.g., 热爱 fervent + love = 'love', 恋爱, long-for + love = 'to have a love affair', 偏爱 slant + love = 'favoritism', 宠爱 pamper + love = 'to dote on'), only whole-word frequency effects were observed on N250s and N400s: high frequency compounds were less negative. When the second morpheme was manipulated, both word and second stem frequency affected ERPs: N250s and N400s were *larger* for compounds with higher second stem frequency, while N400s were unsurprisingly smaller for items with higher whole-word frequencies.[17] Thus, morpheme frequency effects in compounds are different for both languages studied.

A study of Italian compound headedness (77) compared head-initial (*pescespada,* fish + sword = 'swordfish'), head-final (*astronave,* star + ship = 'spaceship', the marked condition in Italian) and exocentric[18] compounds (*cavatappi,* screw + cork = 'corkscrew') using lexical decision. Compounds were displayed as whole words–with standard orthography–or separated into their stems with a space. ERPs showed enhanced and broadly distributed N400s for head-

[17] These results do not appear to be due to an interaction of the two frequency effects.
[18] In exocentric compounds, the meaning of the whole is not related to either of the two stems. Verb + noun compounds are generally considered to be exocentric and do not have "heads".

final and exocentric compounds as compared to head-initial ones, regardless of presentation mode, which suggest that Italian syntax may influence compound structure processing, as head initial compounds align with Italian syntax, but the other two types do not.

2.5.2. Semantic Transparency and Derivation

Semantic transparency effects have been relatively well studied in derivation. Note however that in many experiments, "transparency" is a misnomer: "opaque" items are usually pseudo-morphological since they are monomorphemic (e.g., *corner*, with the pseudo-parse *corn-er*), as opposed to *mistress*, an opaque multimorphemic word. We therefore use the term "pseudo-morphological" where appropriate. An early ERP study (78) investigated whether primed transparent derived (e.g., *hunt-er*), or pseudo-morphological words (e.g., *corner*), are decomposed before lexical access, and thus before access to meaning. Significant and similar negativity reductions in early and classic time-windows (140–260 and 340–380 ms) were found for transparent and pseudo-morphological forms, when preceded by related primes (e.g., *corn* – *corner* and *hunt* – *hunter*), but not in orthographic conditions where a pseudo-morphological parse was unavailable (e.g., *broth* – *brothel*). Only scalp topography differences between pseudo- and truly morphological priming were found, arguing against morphology's special status. A follow-up masked-priming study (79) using stem targets (i.e., *corner* – *corn*) found that pseudo-morphological priming was reduced on N250s and N400s, and less distributed over electrodes, as compared to true morphological priming.[19] This does not support pre-lexical decomposition, as pseudo-morphological priming did not induce similar effects to true morphological ones on N250s. A second follow-up study (80) reinvestigated early N250 effects using two different prime presentation times (50 and 100 ms) and masked-priming in a semantic categorisation task.

[19] However, some analyses appear to show linear trends for semantic priming effects across conditions.

Here, morphological and pseudo-morphological forms patterned together on early N250s (200–250 ms), whereas morphological and orthographic priming patterned together in a later phase (250–300 ms). This argues for rapid morpheme (or potential morpheme) extraction independently of semantic relatedness. Prime presentation time only affected results on N400s, suggesting that N400s are sensitive to strategic effects (see (81–83), for more discussion). Converging MEG evidence from (84) finds equal modulation by real opaque (*department* – *depart*) and transparent morphemes (e.g., *alarming* – *alarm*) as compared to orthographic priming (e.g., *demonstrate* – *demon*). In addition, contrasting pseudo-suffixed to truly-suffixed words (e.g., *brother* vs. *farmer*) reveals that transition probabilities between pseudo- and real stems as well as pseudo- and real suffixes, as well as whole-word frequency, modulate M170s (85), indicating that both stimulus types are parsed early in word recognition but can also be accessed whole, as supported by whole-word frequency effects. These data point to an evolving picture of how opaque and transparent morphemes, and pseudo-morphemes, are processed. In all cases, real morphological processing effects are found, but pseudo-morphemes show varying results depending on prime presentation time, masking, or task. Some authors also confuse opaque and pseudo-morphemes in their studies and use both types within a stimulus list. We will come back to this point in more depth in this section's discussion, but we mention this since mixing word types specifically within "opaque" conditions makes results difficult to interpret.

However, some evidence for automatic processing of *only* morphological vs. pseudo-morphological constituents has been found. A study of English (86) contrasted real prefixed (e.g., *re-fill*) and suffixed words (e.g., *farm-er*) to monomorphemic (e.g., *rotate*, *switch*) and pseudo-morphemic ones (e.g., *reckon*, *winter*). An early right lateralized M170 is found for truly derived forms, but not for pseudo-derived ones. Further, contrasting single-word recognition with transparent (e.g., *farmer*), pseudo-derived (e.g., *corner*) and pseudo-affixed words (e.g., *scandal*, where *scan* is a possible stem, but **dal* is not a suffix), and stem (or pseudo-stem) processing (e.g., *farm, corn, scan,* etc), shows that real complex or pseudo-complex words (*farmer, corner*) elicit stronger MEG activity than monomorphemic and pseudo-affixed forms from 320–365 ms. Pseudo-derived forms (e.g., *corner*) only elicit stronger activation than true derived items (e.g., *farmer*) in later time-windows (400–470 ms), possibly indexing top-down re-composition effects. Thus, early morpheme parsing seems to be limited to words that, on the surface, contain a potential stem *and* a potential suffix.

2.5.3. Transparency and Inflection: Regular and Irregular Inflection

Whether regular and irregular morphology are processed differently has been thoroughly investigated using verb (and occasionally noun) inflection. As with derivation, inflection can also vary in transparency, although the vocabulary used to describe this transparency is usually based on the concept of regularity, which intersects with transparency, default status, and predictability. Inflectional regularity and its interface with orthographic or phonological overlap is explored by exploiting differences between regular and irregular forms, the latter usually having less transparent orthographic or phonological overlap with the base stem. Regular inflection rules are often the default paradigm within a language. They tend to be transparent (in contrast to irregular inflection), are used in novel coinages (e.g., *to fax*) and loanwords from other languages (e.g., *to glean* from French *glaner*), and are commonly used by children in regularization patterns (e.g., *I *seed the bird*). They are often more predictable (or *reliabile*, 70) than irregular or sub-regular rules.[20] Because verbal systems often have regular and irregular inflectional patterns (as in English and German), or even have multiple verb conjugation groups (as in Romance languages), studies have focused on whether these various types are processed in different ways. As with

[20] That is regular but not default inflection (206–208).

derivation, regular, default, and transparent patterns (e.g., *walk – walked*) are expected to be easier to process than sub-regular or irregular ones (e.g., *bring – brought*).

In the domain of verbal inflection, an early study (88) investigated inflectional regularity with long-lag priming (~13 items between prime and target), and found that regular priming reduced N400s for German participle verb forms (e.g., *tanzen – getanzt* 'to-dance – danced'), as strongly as identity priming (*getanzt – getanzt*), while N400 reductions for irregular verbs (e.g., *schreiben – geschrieben* 'to-write–wrote') were not significant. Similar results were found for regular and irregular verbs, versus orthographic control conditions in German and Spanish, providing evidence against orthographic explanations for morphological priming (89, 90).

One study attempted to localize generators for past tense production using ERP and low-resolution electromagnetic tomography (LORETA) during a silent verb generation task (91). One epoch (288–321 ms after stem presentation) showed differential activation for regular and irregular verbs: irregulars showed larger negativities in left temporal electrodes, while regulars showed larger negativities in right frontal ones. The authors explain left-temporal involvement by appealing to more important lexical access procedures for irregular verbs. They tentatively explain right temporal activity for regulars as being linked to executive processes involved in word production tasks that load onto working memory.

Using multiple tasks (sentences, stories, and word lists) can provide support for stability in morphological processing. A study in German (92) probed inflected-verb processing with *-(e)n* or *-t* in participle forms, using irregularized regulars (**geladet/geladen* 'loaded') and regularized irregulars (**getanzen/getanzt* 'danced'). Regularized irregulars consistently elicited frontal left-lateralized LANs[21] (250–500 ms after word onset), and what appear to be N400s in the 500–750

[21] See below in Section 3 for LAN effects and their functional interpretation.

ms time-window, especially in sentence and story contexts, while irregularized regulars did not elicit a consistent negativity: N400-like effects were observed in story contexts only. This provides evidence for stable regularization effects (LANs possibly with a concurrent N400) across tasks, but not irregularization effects, which could mean that participants processed irregularized (novel) forms as being monomorphemic.

Focusing on nominal inflection, a German study compared masculine and feminine plurals typically ending either in *-en* (e.g., masculine *Muskeln* 'muscles') or *-s* (e.g., feminine *Karussells* 'roundabouts'), presented RSVP sentence-finally, with correct and incorrect suffixes (93). Regularized irregulars (e.g., **Muskels*) elicited LANs, while irregularized regulars (e.g., **Karussellen*) elicited N400-like negativities (see also (94) for single word presentation). Case-marking overregularization has also been studied in German (95) using sentences containing objects where 'with' and 'without' license accusative and dative case[22] respectively (e.g., *...ohne die*$_{\mathrm{ACC}}$*/mit den*$_{\mathrm{DAT}}$ *Karton-s/*-en* ... '… with/without the$_{\mathrm{ACC/DAT}}$ cartons$_{\mathrm{ACC/DAT}}$ …'). The authors assume that the dative *-n* suffix in *den*$_{\mathrm{DAT}}$ **Karton-e-n* is recognized and decomposed as a distinct component of a complex suffix morpheme (*-e* 'dative' + *-n* 'plural' 80) before rejecting the error, while in *die*$_{\mathrm{ACC}}$ **Karton-en*, *-en* is simply the wrong plural form. In dative-error contexts LAN-P600s were observed, while in the accusative N400-P600s were elicited, supporting the interpretation that ungrammatical *-en* is processed as two distinct morphemes even though their surface form is the same.

Although studies have, for the most part, established differences between regular and irregular verb, or noun, inflection processing, a possible experimental confound is linked to differences in phonological structures (see e.g., German plurals above). Thus, results found for

[22] *Accusative* is used for direct objects, *dative* for indirect ones.

different inflection types could be a reflection of processing load linked to phonological complexity, although this does not explain differences between accusative and dative -*en* above. Some studies have attempted to control for this factor or integrate it in experimental designs. An MEG study in English compared unmasked priming of morphologically related words with low letter overlap (e.g., *teach – taught*), high overlap (e.g., *give – gave*), to identity priming (e.g., *boil – boil*) (97). In a second experiment, low letter overlap (e.g., *taught – teach*), high overlap (e.g., *gave – give*), regular priming (e.g., *date – dated*), and combined semantic and orthographic (but not morphological) priming (e.g., *boil – broil*) were compared. Earlier M350 onsets for all morphological conditions as compared to control ones were found and, importantly, not in combined semantic-orthographic conditions. Converging evidence for this was found in a subsequent study (98) that focused on the M170 indexing "visual form-based morphological decomposition", roughly equivalent to the early N250 component and found above to be activated for derived words (40). This component was modulated by morphological relationships for irregular verbs as well as regular ones, but not in pseudo-irregular (*bell – ball*) conditions. Furthermore, the M170 effect was modulated by irregular pattern reliability (99), which is also potentially correlated with phonological overlap. Finally, these effects are apparently not restricted to the visual modality, as auditory repetition priming of unmasked regular and irregular past-tense verbs facilitates recognition of present-tense targets (e.g., *looked – look, spoke – speak*) and results in N400 reductions (from 300–500 ms), that are significantly stronger than pseudo-past (e.g., *bead – bee*) and orthographic control conditions (e.g., *barge – bar,* 83). Interestingly, the later N400 (500–700 ms) shows stronger reduction for irregular than regular verbs. Strong irregulars (*spoke – speak*) appear to carry this effect, as weak irregular verbs (e.g., *spent – spend*) did not show significant differences with regulars. A follow-up cross-modal[23] priming study, provides converging results, while eliciting additional fronto-central positivities for orthographic and pseudo-past priming (400–600 ms) (101).

2.6. Discussion: Studies on Single Word Processing

We find that a majority of studies point to early or automatic morpheme processing, but very early effects are also surprising (e.g., early effects for compound stem processing before 200 ms and some reported MMN effects). This would imply word-based decomposition at early form-detection visual or auditory processing stages. Derivation and inflection priming studies highlight the fact that morphological processing is rapid and automatic, that semantic, orthographic and morphological processing are distinct operations in their timing and effects on MEG and ERP activation, as supported by differential N400 – and sometimes LAN – modulation. Some have also found later effects interpreted as morphological re-composition or integration. However, in derivation, the distinction between true morphological versus possible morphological processing (i.e., with pseudo-stems and pseudo-affixes) has revealed some inconsistencies (see also fMRI priming studies, 42, 85). Only one inflection study shows semantic priming effects (55). This specific study had long SOAs, which can promote post-lexical or strategic effects. Orthographic overlap does not appear to drive morphological priming, as shown by studies controlling for or manipulating these factors, as well as other fMRI and PET studies not reviewed here.[24] These

[23] Cross-modal priming (e.g., using auditory-visual prime-target pairs) attempts to avoid purely physical (visual or auditory) overlap effects between prime and target by "eliminat[ing] prelexical, modality-specific components of auditory [or visual] priming–including the priming of acoustic elements, phonemes, and syllables–and instead to limit the effects to the lexical entry." (209)

[24] Some fMRI studies also point to differential regular and irregular priming effects (see 2, for a review), and involve additional languages such as Russian (e.g., 210-213). Some argue that priming effects are linked to quantity of formal overlap rather than morphological priming (210). Early studies using positron emission tomography (PET) found similar results, i.e. distinctions between regular and irregular verb processing (211, 213), but see (212) for contradictory evidence when a randomized design with oral sentence production was used instead of a blocked design with single word production.

morphological effects extend to the auditory modality and to non-linear morphology found in Semitic languages, with some differences. In contrast to derivation and inflection, priming has not often been used to study compound processing. Although less ecologically motivated than reading in sentences, priming allows for close study of morphological, semantic and orthographic processing, which can provide us with clues about cognitive processes underlying lexical access.[25]

Recall that there is some confusion between morphological and semantic transparency in English derivation research. Interesting manipulations of morphological vs. semantic transparency have been run in fMRI studies of Hebrew where morphologically related words can be semantically unrelated or opaque (e.g., *t͡zofen* ‘code’ and *t͡zfoni* ‘northern’ share the same root √t͡zfn) or semantically related (e.g., *t͡zofen* and *hat͡zpana* ‘decrypt’ share the same root, but also have a transparent morphological relationship, see, 202, 103). Additionally, derivational morpho-phonological opacity has, as far as we know, not been probed using ERP or MEG. Morphemes can change their form (a processed called allomorphy) when in contact with other morphemes, and they become phonologically opaque, although their meaning remains constant. Allomorphy can occur on stems (compare *musical* /mjuzikəl/ and *musician* /mjuziʃən/) or on affixes (compare the negative prefix in *improbable* /ɪmprɔbəbəl/ and *irrational* /ɪraʃənəl/): many studies do not control for these effects, which could impact morpheme processing (104).

Constraints on morphological structure have mainly been studied with derived novel forms, usually compared to real existing derived words. Most studies have found sensitivity to constraints on derivation, but in sentence contexts (47) no clear differences between possible and impossible derived forms are observed. Studies rarely focus on productivity, but what appears

[25] See also (214) for Mandarin Chinese compound processing using fMRI. Finnish and Japanese fMRI studies also suggest dedicated areas for inflection processing (215, 216).

from (65) is that irregular inflections are indexed by larger negativities on N250s and N400s, while this is not the case for derived words, which rather show larger negativities for *productive* suffixes. Two studies using fMRI that have investigated productivity and transparency in morphological processing (in English and Polish, 105, 106) show globally divergent results to ERPs, that is no differences between monomorphemic and transparent productive derived forms, and stronger activation for opaque or non-productive items. Intriguingly, in the few derivation studies on morphological constraints, stem violations have been shown to enhance or reduce N400s depending on the study, contrary to inflection violations which almost systematically enhance them. Finally, although morphological parsing seems to occur automatically even with novel forms, it appears that a real stem must be present in a pseudo-word for inflection morphology to be parsed. Finally, few ERP and MEG studies have contrasted noun and verb inflection. Presently it is unclear whether distinctions can be made between inflection processing for different lexical-syntactic categories.

Transparency seems to modulate decomposition in compounds, as some studies observe different decomposition effects when compounds have opaque versus transparent constituents. In derived forms, real and pseudo-morphemic structures (e.g., *farmer* vs. *corner*) show similar effects on early N250s and different modulations on later N400s, with early effects interpreted to reflect automatic parsing of all possible morphemes. There is some indication that this early parsing is constrained such that (i) pseudo-complex forms must contain both a pseudo-stem and pseudo-affix, and (ii) derivation processes must be productive. Within-language headedness differences in compounds could also influence word processing.

Regarding inflection regularity, some studies show differential priming for regular and irregular inflected forms, with irregular priming showing no N400 modulation–or reduced modulation. However, other studies show equal priming for regular and irregular verbs, with possible modulation by orthographic or phonological overlap. One study using a production task finds effects for both verb types with different generators (91). Irregular noun and verb regularisation elicit LAN responses (and possibly N400s) while irregularization usually elicits N400s, both occasionally followed by frontal or posterior positivities. We will come back to this pattern in the next section on sentence processing studies. Very early MMN/MEG responses for regularized forms were found, indicating early recognition of possible stems and affixes.

Few studies specifically focus on productivity in inflection, although predictability measures can tap into productivity. Relatively few ERP and MEG studies have addressed processing differences between inflection and derivation, and none between derivation and compounding. Differential effects of derivation and inflection can appear on early, putatively automatic, ERP components (the MMN), the early N250 but also at later N400/M350 time-windows. All studies but one show larger effects for derivation versus inflection in early time-windows, and two show larger effects for inflection in later N400 time-windows. Inflection productivity seems to reduce observed negativities, and transparency or allomorphy also impact on processing. Other fMRI research not reviewed here also finds dissociations for derivation and inflection (e.g., 107-110).

2.6.1. Issues in Studies on Single Word Processing

Many designs, especially simple lexical decision tasks, contravene the *Hillyard Principle*. Luck explains that "[t]o avoid sensory confounds, you must compare ERPs elicited by *exactly* the same physical stimuli, varying only the psychological conditions" (111 p. 134). Clearly using different stimuli for different conditions contravenes this principle. Even within priming studies where, in principle, it is possible to ensure that all targets are present in all conditions, many researchers create unbalanced designs. Furthermore, some authors do not control for semantic or formal overlap between primes and targets, making it difficult to argue for specific morphological effects. MMN studies should also take care to swap all their stimuli between standard and deviant conditions, in order to unconfound standard and deviant items' physical properties from relevant results. Because of this specific issue, many results remain ambiguous. It is not clear if reported effects are linked to morphological structure or are rather reflections of lexical effects, such as word-category, word frequency, or word length. Because directly comparing different stimuli appears to be unavoidable in some designs, it is the authors' responsibility to convince the reader that they have mitigated lexical effects by tightly controlling for stimulus properties or using statistical methods that can integrate item effects into analyses, as has become more common with mixed linear models.[26]

Another issue is that some studies lack power or generalisability. For example, one reviewed study has only 10 items per condition, which are repeated within lists in order to obtain acceptable signal-to-noise ratios. Such a small number of items calls into question data representativity and external validity. Furthermore, lexical decision with or without priming–the dominant paradigm in the extant literature–has is limits, as its ecological validity is not clear. Naming (reading out loud or picture naming), priming tasks within sentences, discourse comprehension and text reading are promising alternatives to lexical decision (see e.g., 112). However, these approaches pose additional challenges, as they are more likely to induce eye- or articulatory-movement artefacts which are detrimental to EEG recording. They are less problematic for MEG however. Research on inflection can easily use sentence processing experiments with or without error-based paradigms and with subliminal or overt priming. We

[26] Note that using mixed linear models can also cause interpretation issues, as using different intercepts can result in different results. See (186) for a discussion of priming data and models illustrating this problem.

have already presented some studies using sentence presentation for derived or compound words, but the vast majority involve inflection. We now turn to these.

3. Processing Morphology in Sentences

This section presents research on phrases (e.g., noun or verb phrases) and longer sentence contexts where inflection and agreement are implemented. Violation paradigms–that is presenting ungrammatical sentences, usually interleaved with grammatical ones–are quite common. In these, inflection errors in auditory and visual modalities tend to elicit left-lateralized anterior negativities (LANs), bilateral anterior negativities (ANs), or N400s between 300 and 500 ms after stimulus presentation (see e.g., 113-116). These are commonly followed by later positive-going waves (P600s) emerging between 500 and 1000 ms after stimulus presentation (117), especially when performing a task, for example grammaticality judgement (116, 118). Biphasic LAN-P600s or N400-P600s are thought to reflect: (i) rapid and automatic morphosyntactic or lexical parsing indexed by (L)ANs or N400s, followed by (ii) structure integration or reanalysis indexed by P600s.

3.1. Inflection in Sentences

Inflection processing–usually tense or agreement–in sentential contexts has mainly been explored using ERPs, possibly because P600s, often found in sentence-violation paradigms, have no homologous component in MEG. Using sentence contexts has the advantage of being more similar to natural language processing contexts than single or primed word recognition. However, these paradigms, in addition to often using RSVP, usually present participants with less ecological violation paradigms, where inflections might be ungrammatical due to agreement incongruencies (e.g., person, number, or gender errors) or might otherwise be inappropriate given a preceding context. However, we find an abundance of linguistic phenomenon and more cross-linguistic data from morphologically-rich languages in sentence-based studies.

3.1.1. Inflection Regularity Effects in Sentences

As with single word processing, regularity has been studied in sentence processing. For example tense-inflection violations on regular and irregular high- and low-frequency regular verbs, using acceptability-judgement and RSVP (e.g., *The man will* *<u>worked</u> *on the platform*)[27] elicit N400s modulated by verb frequency (they are larger for less frequent verbs, regardless of grammaticality) and P600s modulated by grammaticality (they are larger for ungrammatical sentences, regardless of frequency) (119). Irregular verbs elicit more complex patterns: Interactions between lexical frequency and grammaticality are marginal on the N400 (main frequency effects were observed, as with regulars), while they are significant on P600s: both grammatical and ungrammatical verbs show frequency effects. Furthermore, tense errors on high-frequency irregular verbs (… *will* *<u>stood</u>…) elicit earlier P600s than low frequency ones (… *will* *<u>knelt</u>…). A third experiment directly comparing high-frequency regular and irregular verbs finds that regularity and grammaticality interact such that irregulars show smaller N400s for ungrammatical forms, while in the P600 time-window only grammaticality modulates effects, as in the first experiment. Differences in onset timing argue for distinct morphological processing between high-frequency regular and irregular verbs. However, another study with regular and irregular past tense inflection errors finds that all conditions elicit LAN-P600s with no statistical differences between verb types (120).[28] A third group investigating verb regularity errors, found that, in sentences, incorrect forms elicited LAN-P600s, which were more salient and long-lasting

[27] In this study, separate experiments were run for regular and irregular verbs.
[28] Post-hoc analyses for these differences reported by the authors are not supported by main effects or interactions.

for irregularized forms, but nevertheless observed on all types (121). When verbs were presented in lists, no LANs were elicited on inflection errors, but only P3b-P600s which were longer-lasting for irregularized verbs (*pept, by analogy with *swept*). Thus, contexts in which these errors are presented might push processing towards LAN-P600 patterns (within sentence contexts) or P3b-P600s (in lists).

3.1.2. Constraints on Inflection in Sentences

A few studies have assessed sensitivity to word-creation processes and inflectional legality within sentences. For example, Spanish has more and less productive verb conjugation patterns (e.g., *m**e**dir—m**i**do* 'to-measure–I-measure' follows the frequent e~i vowel-stem alternation). Presenting verbs in RSVP contexts elicits enhanced LANs for suffix violations (e.g., **mides* 'you-measure' for *miden* 'they-measure'), while stem violations (e.g., **meden* for *miden* 'they-measure') *reduced* N400 components (350–550 ms after word onset) in midline and central electrodes, suggesting they were processed as non-words, which is surprising as they remain possible stems in Spanish (122). Both conditions elicited P600s (650–850 ms). However, carrying sentences were different for each condition, making effects difficult to interpret: reduced N400s could also be a consequence of the unbalanced design (i.e., different items in the various conditions). Another study in Finnish presented stem allomorphy errors (i.e., the wrong stem form with correct inflection *<u>laud</u>-a* for *<u>laut</u>-a* 'board') in RSVP contexts (123). Stem allomorphy errors resulted in enhanced N400-like components followed by P600s. Because errors were present on stems rather than inflections, these two experiments more properly link up to derivation studies presented above in single word processing. The N400-P600 pattern is also consistent with lexical rather than grammatical error processing.

3.1.3. Subject-verb Agreement in Sentences

Subject-verb agreement was first investigated using ERPs and RSVP in 1983 (25). Agreement errors, such as *As a turtle grows its shell *grow too*, elicited negativities in similar time windows as the semantic N400 but with smaller amplitudes, and appeared to be more frontal than classic N400s, although component distribution over the scalp was not explored at the time. A subsequent study on Dutch subject-verb agreement showed sustained positivities for number errors on singular verbs following plural subjects (124), while an English study found LAN-P600s for subject-verb number errors interspersed with antecedent number- or gender-agreement error conditions (e.g., *The successful woman congratulated *himself* …), which elicited only P600s (117). This study also demonstrated component task modulations: P600s were larger when participants made grammaticality judgements, while LANs seemed to disappear when no task was given.[29] Other German studies of subject-verb agreement errors find frontal and, in one case, sustained negativities for agreement errors, with either no P600 when there was no task (118) or reduced P600s to at least some error types when there was one (125). In the second study, morpheme salience appeared to modulate LAN-like negativities and P600s. The biphasic LAN-P600 is also modulated by list effects: the less common an error is (i.e., 20/80 vs. 80/20), the larger the LAN-P600 (126). P600s seem to be especially influenced by this modulation (see also 116, 118, 127), which has been argued to be in fact a the P3b (126), i.e. an early subcomponent of the P600 indexing stimulus saliency and participant attention, as well context updating (128).[30]

Cross-linguistically, and also within languages, there are numerous cues for subject-verb agreement. Some studies have focused on these different cues in order to establish whether their function, salience and position might affect agreement processing. Varying cue types for agreement by using overt noun-phrases versus pronoun subjects (e.g., *La viuda* 'the widow' vs.

[29] Only small differences were found in Pz electrodes, 50–150 ms after word onset.
[30] See also (217), directly contrasting P3b and P600 effects for syntactic structure errors.

Yo ‘I’) and person-agreement verb marking (e.g., *lorra* ‘she/he-cries’ vs. *lloro* ‘I-cry’) in RSVP elicits only P600s (500–1000 ms) for agreement errors, followed by late anterior negativities (700–900 ms) that are argued to be linked to working memory processes (129). Marked subjects (e.g., pronoun *Ella* ‘She’ as compared to full noun-phrase *La viuda*) promote ANs in the late time-windows. Recently, a visual-auditory paradigm was used to study subject-verb number agreement in *grammatical* sentences (i.e., number cues in the auditory sentence did not match illustrated depictions of singular or plural subjects) (130). Cues were (i) on the determiner in the subject noun-phrase (e.g., *le/les*, ‘the.$_{SING/PL}$’), (ii) on pronoun-verb liaison (e.g., *elle/s aime/ent* [ɛl(**z**)ɛm], ‘she/they like/s’), or (iii) on verb-final consonants (e.g., *il/s rugit/rugissent* [il ʁyʒi(**s**)], ‘he/they roar’). Determiner-number mismatches elicited N400s (300–450 ms) and late P600s (700–1200 ms), while verb-number mismatches usually elicited biphasic N400-P600s. However, liaison mismatches elicited this pattern only in the plural (Figure 3), while consonant-final changes elicited it in both singular and plural conditions. Furthermore, additional sustained frontal negativities were found in two verb-mismatch conditions, highlighting the fact that different number cues may be processed differently within the same language.[31]

Figure 3 here

Another French study contrasts two agreement-error types: (i) subject-verb number, and (ii) determiner-noun gender (e.g., *Chaque semaine,* *le$_{MASC}$/*la$_{FEM}$ *voisine*$_{FEM.SING}$ **rempliront*$_{PLUR}$/ *remplira*$_{SING}$ … ‘Each week the*$_{MASC/FEM}$ neighbor will-fill*$_{PLUR}$/$_{SING}$ …’), while controlling for sentence position (sentence initial versus final) in an auditory sentence paradigm (131). Globally

[31] We refer readers to the paper for discussion of differing effects across conditions.

verb-agreement resulted in larger effects, as did late-occurring errors. Right-lateralized ANs (400–800 ms after violation onset, e.g., at -*ront* [rɔ̃] in *rempliront*) were found for early verb-agreement errors, and LANs (400–800 ms) for late determiner-noun ones. P600s (400–800 ms)[32] were found for all verb conditions but only on late determiner ones. Note that because the design used only singular subjects, the verb cue might have been highlighted by the experiment. Furthermore, an extremely strict offline filter (1-12 Hz) might have eliminated relevant effects and amplified others (132). However, this study is one of few addressing possible differences between processing strategies for quite different types agreement. Other studies that contrast homogenous agreement types are presented next.

3.1.4. Gender and Number Agreement in Sentences

Intra-nominal (i.e., within noun-phrase) as well as inter-phrasal (across phrase boundaries) gender- and number-agreement have been intensely studied using ERPs. In 1999, a seminal study of Dutch sentences presented RSVP established a typical profile of small (non-significant in sentence-medial contexts) or larger N400-like negativities (in sentence-final contexts) followed by P600s for determiner-noun agreement such as *Cindy sliep slecht vanwege *het/de griezelige droom*, 'Cindy slept badly due to the$_{\text{NEUT/COM}}$ scary dream$_{\text{COM}}$' (113). Similar LAN-P600s were found for these error types in German (114). This second study also showed that P600s but not LANs, contrary to semantic N400s (133), were influenced by cloze probability, in that lower cloze probability errors did not elicit significant positivities. A study on Hebrew subject-verb gender agreement found that disagreeing verbs (e.g., ... *hasaxkan**im*** 'the actors.$_{\text{MASC.PL}}$' /

[32] Both the negativities and positivities were analyzed using the same time-windows. This is because effects overlapped to a large extent while showing different scalp distributions. Analyses thus focused on electrode sets that were selected *a priori*. See (130) for a method integrating all scalp electrodes and subsequently analyzing effects by region based on significant interactions.

*hasaxkan**iot*** ‘the actresses.$_{\text{FEM.PL}}$’ *maksim**im*** ‘enchant.$_{\text{MASC.PL}}$ …’ ‘the actors/actresses were enchanting ...’) elicit N400-P600s as well as early ELANs (134), typically found for syntactic-structure violations (127). Gender-incongruency N400 effects were only found for animate nouns, and P600s were elicited only by incongruent verbs with overt morphological marking (i.e., masculine plural verbs following feminine plural nouns). This astonishing result can be explained by the exclusive use of masculine verbs in this design, thus (i) setting up systematic differences between conditions and (ii) promoting processing strategies (such as guessing)[33] (see 135). An extensive review of visual agreement-processing ERP experiments (115) argues that the most consistent pattern for these error types is a biphasic LAN-P600, with N400s emerging instead of LANs when language typology pushes processing towards the lexical domain (see also Chapter 18). For example, contrasting gender and number agreement with adjectives or determiners in word pairs (e.g., *faro alto* lighthouse high.m ‘tall lighthouse’; *el piano* ‘the.m piano’) and in RSVP (e.g., *El piano estaba viejo y desafinado* ‘the.m piano was old.m and off-key.m’), shows that noun-adjective agreement errors in word pairs elicit N400-P300s while determiner-noun errors elicit additional LANs.[34] In RSVP, both types elicited LAN-P600s, and P600s were larger when errors were presented medially rather than at sentence onset (136). Finally, gender errors elicit later P3s or P600s than number errors. Thus, error type and sentence position seem to promote certain neurocognitive processing strategies over others.

Auditory-visual sentence-picture matching paradigms have been used to probe how expectations can set up grammatical processing. For example, auditory Spanish sentences presented with images semantically or grammatically incongruent after a determiner (e.g.,

---

[33] Thus, when a participant saw a word like *hasaxkan**iot*** ‘the actresses’, they had a likely cue that the target verb would disagree with it in gender.
[34] Note however that the LAN was not observed in an earlier similar experiment (218).

Caperucita Roja cargaba la comida para su abuela en un/a [CROWN/BASKET] *muy bonita*. 'Little Red Riding Hood carried the food for her grandmother in a$_{\text{MASC/FEM}}$ [CROWN$_{\text{FEM}}$/ BASKET$_{\text{MASC}}$] very pretty') (137). Similar N400-P600s were found for semantically and grammatically incongruent images. However, early ANs were elicited on disagreeing determiners presented just before the image, indicating that context constrained expectancies (i.e., here one expects a basket, which is feminine). Using similar stimuli with RSVP presentation, and comparing high- versus low-constraint sentences, the same group (138) showed that gender agreement and semantic congruency both interacted on N400s but not P600s: similar large N400s were observed for semantic and gender + semantic violations as with gender violations alone, while additive P600 effects were observed for gender + semantic violations as compared to simpler ones. Interactions indicate reliance on (and competition for) homologous neurocognitive resources, while additivity does not. Unexpected determiners elicited additional enhanced *positivities*, contrary to the previous study's negativities. The authors explain these differences by appealing to the notion that in the first study pictures did not bear inherent gender and certainly no gender markers (-*a*/*o*). Another Spanish study manipulated post-nominal adjective gender-agreement errors on semantically congruent and incongruent words (e.g., ... *una actitud positive-a/*o / !grieg-a/*o* ... '… an$_{\text{FEM}}$ attitude positive$_{\text{MASC/FEM}}$ / Greek$_{\text{MASC/FEM}}$ …'), finding that both incongruencies elicit N400s as well as P600s, and that sentence constraints modulate early positivities for gender errors: highly constraining sentences unsurprisingly elicit larger P600s (139). Again, no additive effects were found on late P600s, suggesting that similar repair processes were being used for both error types.[35] However, scores were variable on the concurrent judgement task (range 60-91% correct, mean 75%), and no response contingent

[35] Note that this specific result depends on which baseline was used (-100 ms before the target or the N400 peak). We refer interested readers to the article.

analyses was run, suggesting that averaged ERPs reflected, at least partly, different cognitive processes across trials. This is important as agreement-error processing has elicited LAN-P600s for adjective-noun agreement errors in French using auditory-sentence picture matching (116), but P600 amplitudes were larger when participants made grammaticality judgements (see also, 118, for German): when participants simply pay attention to sentences with occasional questions probing their content (116) or watch silent movies (118), P600s became non-significant or disappear, while LANs remain.

3.2. Discussion: Morphology Processing in Sentences

In sentence-processing studies, either LAN-P600s or N400-P600s are observed for agreement and inflection errors, but there is quite some variety in effects found, and research is ongoing as to what may modulate them. Components can differ based on phonological salience, sentence position (late errors typically eliciting stronger effects, possibly due to more important context effects or salience), error type (e.g. number versus gender, or determiner-noun vs. adjective-noun agreement), the category on which agreement falls (adjective, determiner, pronoun or verb), and even on the agreement process within categories (e.g., pronoun-verb liaison vs. verb-final consonant cues, or pronouns vs. noun-phrases in subject position). Effects are modulated by presentation modality–auditory tasks are more likely to elicit sustained effects while visual effects tend to be more "local"–and some studies do not find negativities before P600s (e.g., 129, see 115 for reading studies). Agreement processing in auditory-visual paradigms generally elicits biphasic patterns. Furthermore, when no sentence judgment task is performed P600s can be so reduced as to become non-significant or disappear (116, 118) suggesting that P600s are, at least in part, linked to explicit judgment or error categorization. Other potential sentence constraints might lead to surprisal responses (i.e., P300s),[36] while maintaining ambiguous information in memory during sentence processing might promote sustained frontal negativities (130).

3.3. Issues in Studies of Morphology Processing in Sentences

Beyond issues that have been noted in single-word experiments discussed above, additional issues arise in sentence-based designs. Importantly, some experiments use unbalanced designs. When inflection errors only appear in some sub-conditions it could be that elicited ERPs are modulated by participants' expectations, that is they come to expect errors when presented with specific stimulus types. In these cases it becomes unclear whether differences between conditions are linked to experimental conditions (correct vs. incorrect) or rather to differences between target stimuli (for example, only plural sentences containing errors).

4. Morphological Processing in First Language Acquisition, Second Language Learning, and Multilingualism

Neurophysiological studies of morphology have also focused on L1-language acquisition in children, and bilingual language processing or L2-language learning in adults. This research addresses (i) whether children go through structural changes in their ERPs as they mature, (ii) whether neurocognitive changes in children and adult L2-learners are similar in nature, (iii) whether, when learning languages later in life, L2-learners can acquire implicit linguistic word-structure rules (140), and (iv) whether one's multiple languages interfere or compete during morphological processing.

4.1. Morphological Processing in Children

[36] But see (121) who observe positivities for over-regularizations and irregularizations in list contexts *even* without sentences.

Most studies on children presented here also include groups with language or reading/writing impairments. In this chapter, we only highlight typical language development and refer interested readers to original articles, to Chapter 24 and (141) for studies of children with language impairment. Most studies focus on subject-verb agreement.

4.1.1. Compounding in Children

Testing the ability to build compounds according to the rules of English, children aged 8–12 were asked to delete plural markers on regularly inflected nouns (e.g., *boys*) or irregulars (e.g., *men*) and then compounded these by inverting the stems (e.g.*,* FEED + BOYS → *boy feeder*). The paradigm elicited a delayed and less focal pattern than that found in adults (negativities 800–900 ms) for regular plurals versus irregulars (e.g.*,* FEED + MEN → *man feeder*) (142). Cantonese-Chinese children aged 8–10 also show sensitivity to structural constraints for compounds, eliciting significantly larger and sustained N400s for reversed (洋海 from 海洋 'ocean+sea' = 'ocean'), than for real (房屋 'building+house' = 'housing') and novel printed compounds (架旅 from 架 'fight' and 旅 'travel') (143).

4.1.2. Inflection in Children

As mentioned, studies on inflection in children focus mainly on subject-verb agreement. Interestingly, most research highlights different processing patterns in children below 8-years-old versus those above it, when they start to converge on adult patterns. These ongoing changes might reflect numerous neurocognitive processes, such as grammatical automatization, growing working-memory or vocabulary, brain specialization, or simply practice.

A study of subject-verb agreement (144) in Italian-speaking children aged 8–13, with auditory sentence presentation and grammaticality judgements, investigated singular (e.g., *La* *bambina bionda* *<u>gioc**ano**/gioc**a**</u>* ... 'The blond girl *<u>play/plays</u> …') and plural subject-verb agreement. Children elicit significant P600s (700–1000 ms), similar to adults although delayed, but no negativity, contrary to adults who show negativities only for singular errors in plural sentences (145). Unfortunately, no analysis of number effects was included in the child study.[37] An English study does contrast these effects while focusing on possible differences between commission (i.e., adding superfluous morphemes, as in *The boys often *<u>cooks</u>* ...) and omission errors (i.e., omitting obligatory morphemes, as in *The boy often *<u>cook</u>* ...),[38] as well as sentence-position (medial vs. final contexts), using auditory sentences presented concurrently with images (146). Both error types elicited biphasic AN-P600s in adults, and, unsurprisingly, sentence final errors elicited larger P600s. In 9–12 year-olds only commissions elicited N400s, and sentence position did not influence component amplitudes: thus phonological salience appears to be more important than sentence position for children (147). However, another study of children aged 7–11;5 years showed that sentence structure can affect subject-verb agreement processing (148). In this case participants elicited delayed ANs (575–775 ms) followed by P600s (700-1200 ms) for errors in canonical sentences (e.g., *Every night they <u>talk/*talks</u>* ...), but only P600s and non-significant ANs in so-called long-distance conditions (e.g., *He makes the quiet boy *<u>talks/talk</u>* ...).[39] Another study shows that similar agreement errors in short sentences elicit only sustained P600s in 16-year-olds (149). As with (146), this last study compares commission and omission errors: they report similar P600s for both. No mention is made of negativities, although

---

[37] Children are known to default to the singular, and thus results might have varied based on this feature.
[38] Contrary to most languages with inflection, the 3rd person singular in English carries more morphological information than the plural.
[39] "Long distance" is not really what is making these sentences more difficult to process, but rather their syntactic structure (*accusativus cum infinitivo*) linked to certain verbs and causative clauses that demand accusative objects which, in turn, subcategorize for uninflected *infinitives* (*He makes <u>him talk</u>*), ***not*** present tense forms, as the authors claim. Furthermore, these sentences might induce attraction effects due to intervening noun phrases before the verb. See (219) for attraction effects in children and adults.

the same team previously found *only* right-lateralised anterior negativities (RANs, 350–550 ms) and non-significant P600s for these conditions in 14–18-year-olds (150). Thus, data on subject-verb agreement in children and adolescents remains unclear. Most studies find effects–possibly modulated by morpheme salience or sentence position–indicating sensitivity to errors, but effects vary in presence, polarity, and timing across studies.

4.1.3. Other Studies of Morphology in Children

A few studies have focused on other aspects of inflection morphology in children. These include plural marking, gender agreement and tense production. *S*-plural overregularization in German (e.g., ... *die grossen *Apothekes/Apotheken* ... '… the large pharmacies …') has been studied in children aged 6–12-years-old (151). Younger children elicit broadly distributed negativities emerging at 400 ms, children aged 8 exhibit ANs, and 11–12 year-old children exhibit ANs followed by late positivities at 1000 ms–similar in distribution to adults' LAN-P600s in the same conditions (152) but with longer latencies. Note that errors always occurred on nouns with *s*-plural overregularizations, potentially inducing processing strategies as well as systematic differences between ERPs in both conditions.[40]

Bimodal auditory-visual presentation (e.g., *Je vois *une/un soulier brun/*brune sur la table* 'I see *a.f/m brown shoe on the table' picture: [BROWN SHOE ON TABLE]) focusing on gender agreement in French in children aged 4–9 elicits P600s following determiner-noun gender errors (1250–1350 ms after noun onset), similar to adults but delayed (153, 154). Adjective-noun agreement errors elicit biphasic N400-P600s similar to adults, while negativities are less lateralized and are slightly delayed (500–650 ms) (116). However, P600s are non-significant, a result that might be linked to small participant groups and averaging across wide age-ranges, but

[40] The authors also do not discuss *-en* irregularization patterns, which they also presented to participants.

also the absence of a task (116). However, new analyses by the same involving more participants and controlling for age and meta-linguistic abilities reveal that P600s correlate with off-line behavioural responses, and that children with lower meta-linguistic abilities elicit frontal P3a's (i.e., responses linked to surprisal) rather than P600s (155), thus explaining non-significant effects in the first analysis.

Finally, sensitivity to verb-inflection regularity in children has been studied by using delayed production, cuing past or present tense regular and irregular verbs from the infinitive (e.g., visual: to eat → past cue → oral production: *ate*), in L1-English children, and L1-German-L2-English learners, as well as adults (156). Adults show enhanced frontal negativities (300–450 ms) for irregulars, as did L1-English children aged 12 on average, but not younger L1-English children aged 8.[41] L1-German children show converging effects, despite higher error rates in production (157). Larger N400-like negativities for past-tense irregular-verb production are found in L2-English, and frontal negativities for regular weak-verb past-participles in L1-German (e.g., *lach – lacht* 'pull – pulled')–similar to German and English speaking adults–as well as globally delayed N400s (after 700–800 ms). Thus, monolingual and bilingual children appear to be able to distinguish verb inflection types in English and German (or both) but show delayed ERPs in comparison to adults. We now turn to adult studies on L2-processing.

4.2. Morphology in Second Language Learners

We make a simple distinction here between early (or simultaneous) bilinguals who learned both their languages at young ages, and (sequential) late L2-learners who learned their second language later (this can vary from study to study, see Chapter 21, and 124 for extensive reviews).

[41] Note that on average, only 22 items were analyzed by condition in child groups due to artefacts (adults retained 28–30/40 items per condition). Similar issues arise in another study (220).

Although early bilinguals and multilinguals are quite common in terms of world population, most research on bilinguals has focused on late learners exposed to their L2 in adolescence or adulthood. This might be linked in great part to interest in the Critical Period Hypothesis (CPH) and the search for brain patterns reflecting it or not. The CPH posits that if one learns an L2 after a certain age, it is impossible to attain native-like linguistic abilities due in part to loss of brain plasticity (but see Chapter 21 for discussion). As we will see, studies on morphological processing present conflicting data on the CPH, some supporting the notion that L2-learners can converge on native-like patterns (140).

4.2.1. Compounding in Second Language Learners

Sensitivity to constraints on compound structure have been investigated in proficient L2-English, Spanish and German L1-speakers, using mask-primed delayed lexical decision (158). Novel compounds presented with their constituent nouns in reversed orders (*dust coal*) elicited N400s followed by positivities in L1-English speakers, delayed and sustained N400s in German L1-speakers, and delayed N400s in *licit* (*coal dust*) word orders in Spanish L1-speakers, coherent with Spanish grammar, who however elicited positivities for *illicit* English compounds. Compound frequency predicted N400 amplitudes for licit word orders English L1-speakers, but for reversed constituent orders in Spanish L1-speakers, suggesting interference from the L1 to the L2. Silent and overt compound and inflection production has also been studied using the procedure described above for children (e.g., FEED + BOYS → *boy feeder*, 159) in adult German-L1 English-L2-speakers and L1-English. Regular plurals elicited larger right ANs than irregulars during silent production in both groups. In singular conditions (e.g., FEED + MAN → *man feeder*) no differences were observed in ERPs or overt production, either within or across groups. These two studies appear to indicate that L1-grammars might influence L2-structure processing by either aiding processing when they are congruent, or interfering when they are not. Furthermore, sensitivity to distinctions between regular and irregular inflection seems to be available to both L1- and L2-speakers.

4.2.2. Derivation in Second Language Learners

In order to evaluate sensitivity and use of morphological structure as a cue to word recognition in L2, the Dutch study by (65) above also evaluated Turkish-L1 Dutch-L2-speakers with productive and less productive derivations (e.g., *dreig-ing* 'menace' vs. *stoor-nis* 'disorder'). Similar negative brain responses were elicited in both participant groups. However, presentation contexts affected negativities differently in both groups. L1-Dutch speakers showed larger early negativities (350–500 ms) for derived words within lists of novel words containing possible stems and suffixes (e.g., *duur-heid* 'expensive'), and only L1-Dutch speakers elicited larger positivities (500–700 ms) in these contexts. No differences between groups were found when words were presented in lists containing non-decomposable nonwords (e.g., **shirsan*). The authors argue that N400 amplitude differences between groups are linked to automatic morphological decomposition in Turkish-Dutch speakers–that is they are less affected by context effects than L1-Dutch speakers–while the later positivities reflect native speakers' sensitivity to productivity during stem + suffix recombination processes. This means that Turkish learners of Dutch might be so used to automatic morpheme decomposition in their morphologically-rich L1 that they apply a similar word-recognition strategy to their second language, unlike Dutch native speakers.

Recently, a study of beginning and advanced L1-German L2-Finnish learners examined sensitivity to morphology types using a passive auditory oddball task. They presented stems as standards (e.g., *kuva* 'picture'), and suffixed forms as deviants (e.g., derived *kuvasto* 'picture book', or inflected *kuvasta* 'of-the-picture') (160). Fillers included non-existent suffixed forms with similar phonology (e.g., **khavisto* 'collection of coffee') and stems with pseudo-suffixes (e.g., **khavispa* 'coffee-spa'). Both derived and inflected words elicited early positivities (60 ms after suffix onset) distinguishing suffixed forms from monomorphemic ones. This effect did not differ among language groups. Derived forms elicited larger anterior negativities than inflected forms in native speakers (~160 ms), and, intriguingly, in beginner L2-learners but not advanced ones (they showed non-significant trends). However, multimorphemic forms were always deviants in this paradigm, making data interpretation tentative and problematic.

4.2.3. Inflection in Second Language Learners

Investigating the use of inflection processing as a strategy to recognize verbs, a French masked priming lexical-decision study in L1-English L2-French adults presented identical, morphological, semantic, and orthographic priming conditions to low-to-high proficiency L2-learners and L1-French controls (161). Similar to (56) they found morphological priming beyond orthography and semantics, with the additional results that (i) identity and stem morphological priming both attenuated N400s to the same extent, and (ii) L2-French-speakers showed equivalent N250 and N400 modulations, irrespective of proficiency, suggesting that even intermediate L2-learners are able to processes inflectional morphology online.

Sentence processing has also been used to investigate morpho-phonological and morpho-syntactic error processing in bilinguals (see also Chapter 21). Using RSVP, and comparing L1-Russian intermediate-L2-German speakers to German L1-speakers from (92), it was shown that L2-speakers process regularization and irregularization errors similarly to natives, eliciting bilateral ANs followed by P600s to regularizations (e.g., **gelauft* / *gelaufen* 'run') and only broad P600s for irregularizations (**getanzen / getanzt* 'danced') (162). However, different patterns were found for noun-plural errors where, contrary to L1-speakers, L2-participants did not elicit a frontal negativity for -*s* plural overregularizations. Coherently with this verb data, another study (163) found that proficient adult L1-English L2-Spanish learners displayed LANs, P600s, and late negativities for number and gender determiner-noun agreement violations, similar to L1-speakers. However, they failed to elicit "native-like" LANs for long-distance noun-adjective agreement, which could be explained by lower judgment accuracy for gender but not number errors in L2 participants. The latter finding suggests that language proficiency alone does not always fully predict ERP profiles. A follow-up study by the same group (164) with proficient L1-Chinese L2-Spanish learners found P600s and late frontal negativities, but no LANs for any type of agreement violation. The authors attributed differences between their two studies to transfer effects from L1s. Other agreement studies have shown that phonological transparency (or saliency) affects L2-learners' (and even L1-speakers') ability to process inflection, including in silent reading (165, 166). In general, P600 effects are more reliable especially in L2-learners if the orthographically marked violation is phonologically realized. These data show that opaque inflection is harder to process both in L1 and L2, and that different L2-groups show variable patterns, depending on their L2-proficiency and their L1 typology.

A considerable number of agreement-processing studies have tried to clarify how similarities between L1 and L2 may influence the acquisition and processing of one's L2, especially regarding grammatical gender (167–172). A consistent finding has been that clear conflicts between a noun's idiosyncratic gender in L1 and L2 results in major L2 processing difficulties (e.g., 'the moon' is feminine in French, *la lune,* but masculine in German, *der Mond*), highlighting the fact that L1 information is quite possibly co-activated during L2 processing, promoting L1 to L2 transfer. Interestingly, if L2-learners erroneously overgeneralize a noun's grammatical gender from their L1, they may show a P600 for the objectively correct (but subjectively incorrect) determiner-noun combination (171). This illustrates the importance of careful ERP data analysis: simply analyzing items according to objective measures of grammaticality may result in null effects and (falsely) suggest that L2-learners don't process gender agreement at all.

As phrase structure complexity is expected to impact on L2-processing, some studies have manipulated syntactic contexts for agreement. This was examined on number and gender agreement in L1-English L2-Spanish speakers by contrasting intra-nominal (e.g., *… órgano muy complejo/*a* '… organ$_{\text{MASC-SG}}$ very complex$_{\text{MASC-SG/*FEM-SG}}$') and inter-phrase agreement (e.g., *cuadro es auténtico/*a* '… painting$_{\text{MASC-SG}}$ is authentic$_{\text{MASC-SG/*FEM-SG}}$') using RSVP (173). Spanish has a richer agreement system than English with, in addition to number agreement, gender agreement on adjectives, determiners and so on. Despite cross-linguistic differences, advanced L2-learners elicited P600s for both violation types, and longer distances between agreeing elements reduced P600 effects in both groups. Two other studies evaluate L2-learning using an artificial language to control for language exposure (174, 175). Implicit versus explicit instruction contexts–mirroring natural language learning versus classroom instruction–were implemented. These studies found that ERPs to gender-agreement errors depend on learning conditions, despite the fact that both groups could equally identify ungrammatical structures on off-line measures. At low proficiency, gender-agreement errors elicit N400s *only* for noun-adjective agreement errors in the explicit group, while the implicit group elicited N400s for *both* noun-adjective and noun-determiner agreement-errors. At high proficiency, both groups elicited similar ERPs: P600s for noun-determiner violations, and N400s for noun-adjective violations. Thus, not only the structure tested affects neurocognitive processes underlying language comprehension, but the type of L2 learning impacts ERP components, providing evidence for brain plasticity in L2 acquisition.

Finally, some research is interested in whether bilinguals "lose" native-like morphosyntactic processing abilities in their L1 when they become L2-dominant, that is whether brain plasticity can influence the L1. A study on L1-attrition investigated whether L2-language learning in adulthood may affect one's L1 by probing Italian subject-verb agreement and long-distance noun-adjective agreement violations in L1-Italian speakers and L1-attriters (176).[43] Unlike studies reported above, this was evaluated in the *first* language. Agreement violations such as *Il lavoratore *tornano dalla fabbrica *sporchi di grasso* 'The worker.$_{SG}$ return*$_{PL}$ from the factory dirty*$_{PL}$ with grease' elicited biphasic ERPs in both groups, but scalp topography, amplitude, and ERP component timing significantly differed between monolinguals and attriters (Figure 4). Importantly, these group differences were correlated with the time participants spent speaking their mother tongue, a finding that has since been replicated with other (morpho)syntactic structures (177). These data indicate that brain plasticity in adulthood allows for changes even in one's L1-grammar, and that degree of change depends on relative use of one's L1 and L2.

Figure 4 here

There is some controversy as to whether early bilingualism affects how we process language, and studies of early bilinguals are rare. One priming study by (178) with L1-Catalan-L2-Spanish and L1-Spanish-L2-Catalan early bilinguals evaluated sensitivity to verb regularity in Spanish. While regular verb priming showed similar N400 reductions in both groups, semi-regular verb priming reduced N400s only in L1-Spanish speakers, while L2-Spanish speakers showed less priming for both semi-regulars and irregulars, supporting subtle differences in verb

[43] Native Italians who reduced their exposure to Italian in adulthood having lived more than 10 years in an English-L2 environment.

morphology processing even within early bilinguals. However, some Catalan-dominant speakers self-rated as using Spanish rarely, possibly causing observed differences.

4.3. Discussion: Morphological Processing in First Language Acquisition and Second Language Learning

Research on children, although sparse, seems to indicate component latency decreases and increased focalization as children mature, in addition to less reliable effects for ANs than for P600s, at least in younger children, the former possibly appearing only after age 7 or 8. This pattern resembles some effects found in adult L2-learners, that is moving from N400-like responses towards posterior positivities or frontal, often left-lateralized, negativities for inflection processing. Some domains seem to mature earlier than others, but most inflection processes appear to do so after age 8, much later than ages where children are believed to have mastered their mother tongue. The data also indicate different processing strategies or at least focus on different cues by children and adults. However, some results remain contradictory or surprising.

ERP studies on adult L2-processing provide us with tantalizing evidence regarding the critical period hypothesis. On the one hand, some priming studies show that L2-learners can process morphological structure in single words similarly to L1-speakers, while other sentence-based paradigms show that L2-speakers can process errors but sometimes differently from L1-speakers. These differences can be modulated by correspondences between L1 and L2 grammars (transfer), and proficiency in the L2 grammar (or attrition in L1 use).[44] Morphological processing studies in early bilinguals–that is people who were first exposed to their L2 in infancy or early

[44] An fMRI study investigating highly proficient bilinguals suggests that language typology (i.e., richer vs. poorer morphology) might influence sensitivity to, or parsing strategies for, inflection morphology (221).

childhood–are rare, which is astonishing, since bilingualism and multilingualism are quite common globally, and represent at least 50% of the world population (179).[45]

An issue pertaining to bilingual, multilingual, and child populations is that groups are quite heterogeneous. Studies on L2-learners often present data form a variety of learners (beginner, intermediate or advanced) and do not provide a clear picture of how different language-attainment levels can modulate brain behaviour (140). Some adult-L2 studies fail to match their groups on proficiency (or alternatively, to integrate proficiency in their analyses). The same could be said of some child language studies where large age ranges are included, without making provisions for maturational effects on language processing. In both cases, differences based on proficiency might be washed out by averaging.

5. General Discussion

Bringing together the reviewed studies, we can assert that most point to rapid and automatic processing of morphology by the brain. That is, morphology is a real brain-based construct and not an epiphenomenon of semantic or formal processing. This is especially highlighted by lexical decision and priming studies. However, we also can reasonably assert that not all morphology types are processed in the same manner: we find that ERP and MEG components differ depending on stimuli types, presentation mode, and task. Thus, presentation of single decontextualized words might promote morphological analyses, especially if stimuli are derived or compound forms, because participants are focussed on judging their word-likeness within lists of similarly-structured words. In contrast, decontextualized inflected words, with no sentence context, might not promote in-depth analyses of grammatical information. In many single-word

[45] See also an fMRI study showing that morphological parsing strategies for derivation in two different languages may differ within the same Hebrew-English bilinguals (222).

studies, the N400 is the dominant ERP marker of morphological processing. However, when impossible or ungrammatical stem + suffix combinations are provided, components more akin to sentence-processing violation paradigms are elicited. Thus, even when studying single words, multiple ERP components can be elicited during morphological processing.

Regarding inflection in sentences, we have observed again that multiple components are elicited by (dis-)agreement, for example LANs, sustained ANs, N400s and P600s. There is no clear consensus yet on how to interpret these results due to controversies about what these components represent (see e.g., 180, 181 and Chapter 18). One perspective on inflection-error processing suggests that reliance on highly regular morpho-phonological markers elicits LANs, while retrieval of additional lexical information (e.g., about the word stem) tends to yield N400s (115), reminiscent the distinction between lexicon-based and rule-based processing (182). What seems uncontroversial at this point is that these components (LANs, N400s, P600s) are not specific to morphological processing. They are similar to those found in other contexts, such as syntactic error processing, in terms of polarity, scalp distribution, and timing (e.g., 118).

There are numerous challenges to the neurophysiological study of morphology: these include linguistic and psycholinguistic factors, populations, methodological, and statistical considerations. Since we know that morphological regularity, pattern frequency, morphological complexity and transparency (word and stem), as well as word length, syntactic category, sentence structure and other factors may influence elicited components, it is important that we pay attention to these when developing our experiments. This is an important concern if one wishes to develop more ecological paradigms with sentences, paragraph reading, or comprehension tasks. It is much easier to control for single word properties than for those encompassing sentence and information structure. Furthermore, within sentences, one should control for context priming effects that are expected to impact on target word processing (e.g., 183, 184). Presenting target stimuli early in sentences in order to avoid context priming effects on their targets is one solution to this problem (74). Regarding populations, a majority have relied on healthy, young, and literate, adult university students (also known as WEIRD populations, i.e. *Western, educated, industrialized, rich, democratic* 185). Middle-aged and older populations as well as teen-agers and young children are under-represented, as are most of the languages of the world. Children and L2-learners appear to be sensitive to morphological structure, but might pass through a sequence of neurocognitive processing stages before they exhibit native-like or adult patterns. Older adults might or might not maintain morphological processing skills: the present reaction-time and behavioural data are unclear on this issue and would benefit from complementary neurophysiological studies (186). Although these specific groups present extra challenges for neurophysiological research, they also provide fruitful information about different cognitive stages humans go through during language learning and through the lifespan.

A final challenge is that some results in ERP or MEG studies do not seem to be sufficiently supported by statistics (i.e., main effects or interactions), and effects are sometimes decomposed without support from global ANOVAs (or linear models). Adhering to sound scientific principles regarding data analyses is necessary. Some studies also report high error levels but do not adapt their analyses to this reality. Using response-contingent analyses, either alone or in contrast with response non-contingent analyses, can help resolve the question of whether high levels of error are reflected by different ERP patterns (e.g., 168).

5.1. Future Neuroimaging Studies on Morphology

We observe a growing variety of languages and their morphological structures being studied. However, there are still very few compounding studies using neurophysiological techniques, and few languages have been studied in that specific domain. A larger corpus of ERP and MEG research devoted to derivational morphology on Finnish, in addition to Indo-European languages is found (mostly English, but also Dutch, French, and German). However, apart from English and Finnish, there are usually only one or two studies in other languages. Emerging research programs are presently pursuing morphological processing in less-studied languages (e.g., Arabic, Japanese, Mandarin, and Tagalog, 1, 59, 187-190). In particular, Semitic languages, as well as reduplication processes, challenge linear approaches to both derivation and inflection morphology. Finally, inflection studies are quite linguistically varied, and show potential for cross-linguistic investigations in more "naturalistic" contexts, with however the caveat that some languages do not use inflection morphology at all.

Taking advantage of linguistic structures that are specific to some languages (e.g., reduplication) will allow us to better understand morphological processing in the brain. In addition, focusing on symmetries that exist within languages might also enable us to better understand distinctions between syntax and morphology. For example, compound structures which mirror syntactic ones (e.g., paralexemes common in Romance languages such as French *pomme de terre* literally 'apple of earth' = 'potato', or English *black bird* vs. *blackbird*) could be investigated. Whether compounds are processed as lexical units or syntactic ones (e.g., adjective-noun structures such as *blackbird* could be processed as syntactic noun-phrase structures – adjective (*black*) + noun (*bird*) – similar to *old bird*, or alternatively as single lexical units) has not been addressed in ERP research, as far as we know. The parallel or disconnect between compounds and other syntactic structures seems fruitful for the investigation of compound processing. Stress is crucial to distinguish these structures: word and sentence stress are different in the case of *black bird* – *blackbird* (191). There is ERP data supporting stress's importance for agreement processing in German compounds (192).

Complex derivational structures, such as *un-de-compose-able*, with rich word-internal hierarchical structure, have also not been studied using ERP or MEG (but see e.g., 193, 194 for fMRI data). Because these word types are common in morphologically-rich languages (e.g., Turkish and many of the world languages, including indigenous languages of North America) their study could highlight important cognitive processes in word processing. It would be interesting to know whether they are fully decomposed, processed as chunks without internal structure, or processed variably depending on the frequency with which morphemes co-occur, as has been suggested for less complex words (195). Hierarchical structure (e.g., *un-lock-able* can be parsed as the suffixed verb $[\text{un-lock}]_{\text{V}}$ + able 'possible to unlock' or un + $[\text{lock-able}]_{\text{Adj}}$ 'possible to lock', (196), as well as working memory, known to influence sentence parsing even in L1-speakers (197) may also modulate complex word processing.

It stands to reason that inflection most often needs more than single words to be processed (when checking agreement, although not always for tense) and therefore must be presented in sentence contexts rather than in single word presentation. Single word presentation might not tap into potentially important differences between morphology types–i.e., derivation, compounding and inflection–which have often been compared in this way. Thus, developing more naturalistic presentation paradigms might be relevant for research on morphological processing (112). Innovative research will possibly involve using longer-than-sentence contexts with paragraphs or spoken texts. Presently some syntax studies involve short context sentences before target ones, establishing referents and pragmatic, as well as semantic, information (e.g., 197). Other studies on agreement have used visual-auditory paradigms to create cross-modal mismatches with perfectly grammatical sentences, as in story-telling contexts (130), or ungrammatical sentences within alien-learning paradigms (198), allowing for contextually plausible incongruencies to emerge.

ERP and MEG research on morphology has been less used with patient populations than fMRI (see 199, and Chapter 24) and is not yet common in language acquisition. However, these domains introduce many interesting avenues for research. Children have the potential to help us better understand how adult L2-learners differ (or not) from L1-speakers in their learning behavior. Observed changes in child language learning appear to mirror L2-language learning, but no direct comparisons have been made, and these similarities might be superficial. Patient studies of inflection processing have historically focused on distinctions between syntactic categories (e.g., on nouns vs. verbs) reflecting patient dissociations in abilities to process these categories and their inflections (see e.g., 200). However, ERP and MEG studies have typically not focused on this question.

In sum, there are many questions related to morphological processing that remain to be explored using ERP and MEG. Research from the past 35 years has identified factors that facilitate or mitigate morphological processing in words and sentences. We see great potential for studies developing paradigms involving grammatical sentences, text and discourse, as well as more varied populations including ageing adults, multilinguals, children, teenagers and patients speaking non-Indo-European Languages.

Figure 1

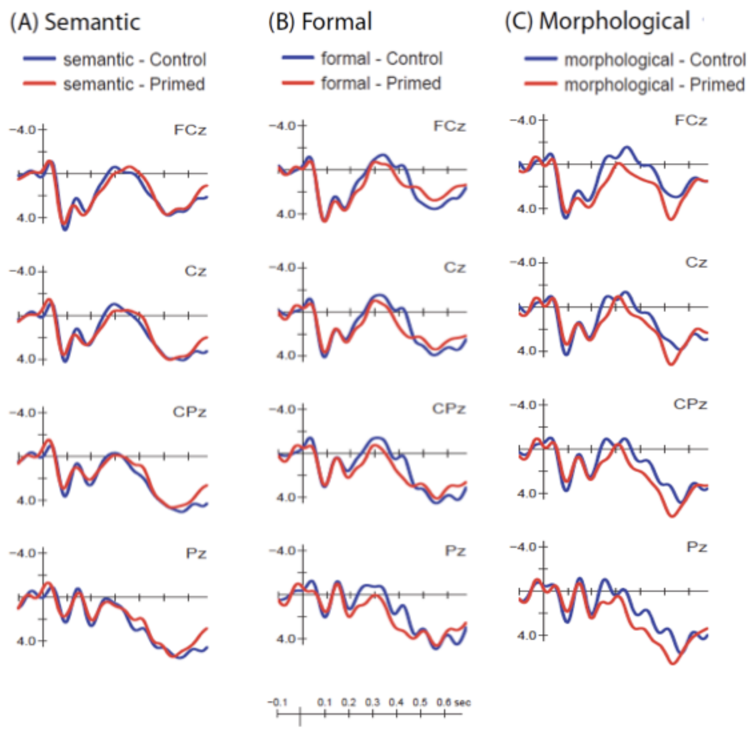

Figure 1. Adapted from (56), Figures 2 and 3. Grand average waveforms for (A) semantic, (B) formal, and (C) morphological priming conditions. The masked priming paradigm successfully inhibited semantic effects, as there were no significant differences in A A for any time-window. Both formal and morphological ERP priming effects–N250 and N400 reductions– were obtained. These overlapped between 175-450 ms (in B and C). Between 450-550 ms only morphological priming effects were evident (in C).

Figure 2

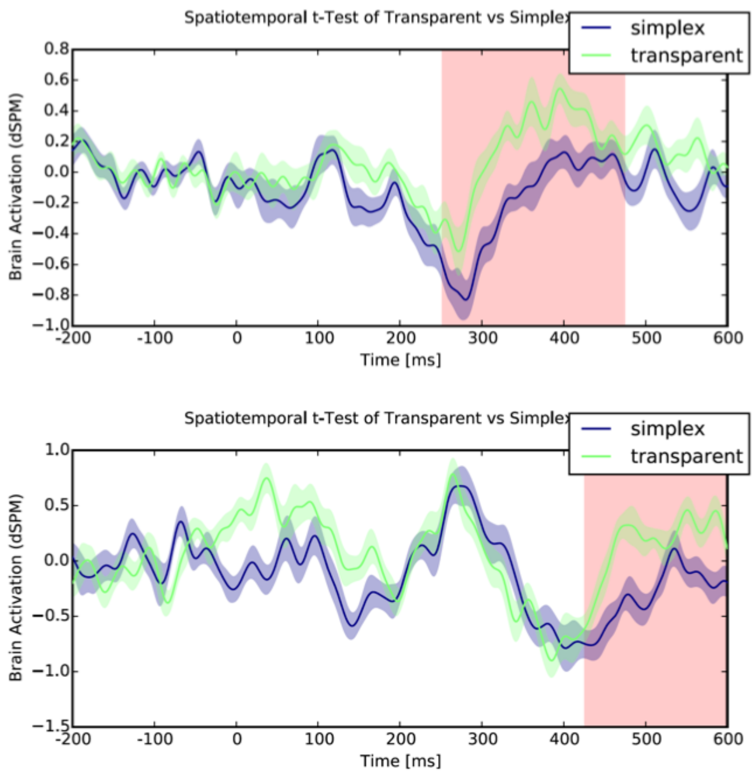

Figure 2. Adapted from (72), Figures 3 and 4. Morpheme vs. Form priming. Transparent morphology vs. Form priming ("simplex") effects on MEG in the left anterior frontal lobe (250–470 ms, top) and posterior superior temporal gyrus (430–600 ms, bottom). Stronger activations are found for transparent morphological priming in the form of heightened activation (green lines), significant windows are shaded in pink.

Figure 3.

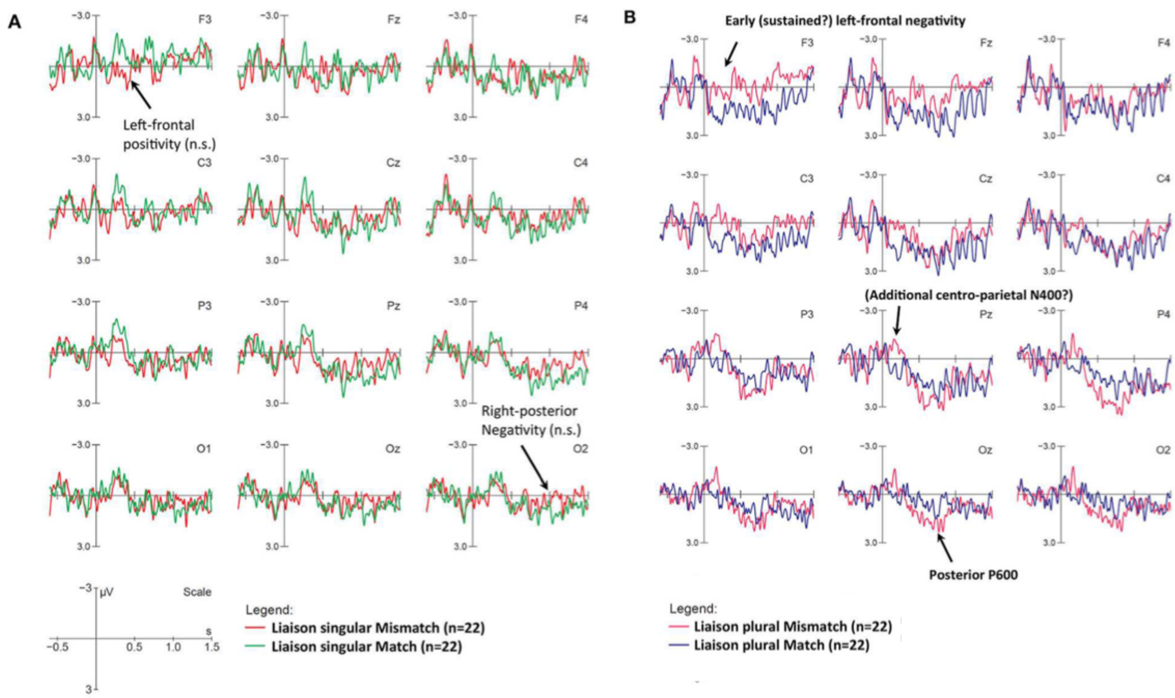

Figure 3. Adapted from (130), Figure 5. ERP effects for number mismatches at liaison verbs in neutral contexts for singular (A) and plural (B) verbs. Displayed are grand-average ERPs at midline and lateral electrodes for all participants, time-locked to the onset of the liaison /z/ in plurals (*elles aiment* [ɛl**z**ɛm], 'she/they like/s') using a baseline of -600 to 0 ms. The vertical bar marks liaison onset. (A) For singular verbs, neither the early frontal positivity between 150 and 450 ms nor the posterior negativity (1,000–1,200 ms) reached significance. (B) Compared to the correct control condition (blue lines), plural mismatches (magenta lines) showed early negativities (100–300 ms), followed by a posterior P600 (500–900 ms). After the end of the P600, a negativity appeared to re-emerge at frontal and central electrodes.

Figure 4.

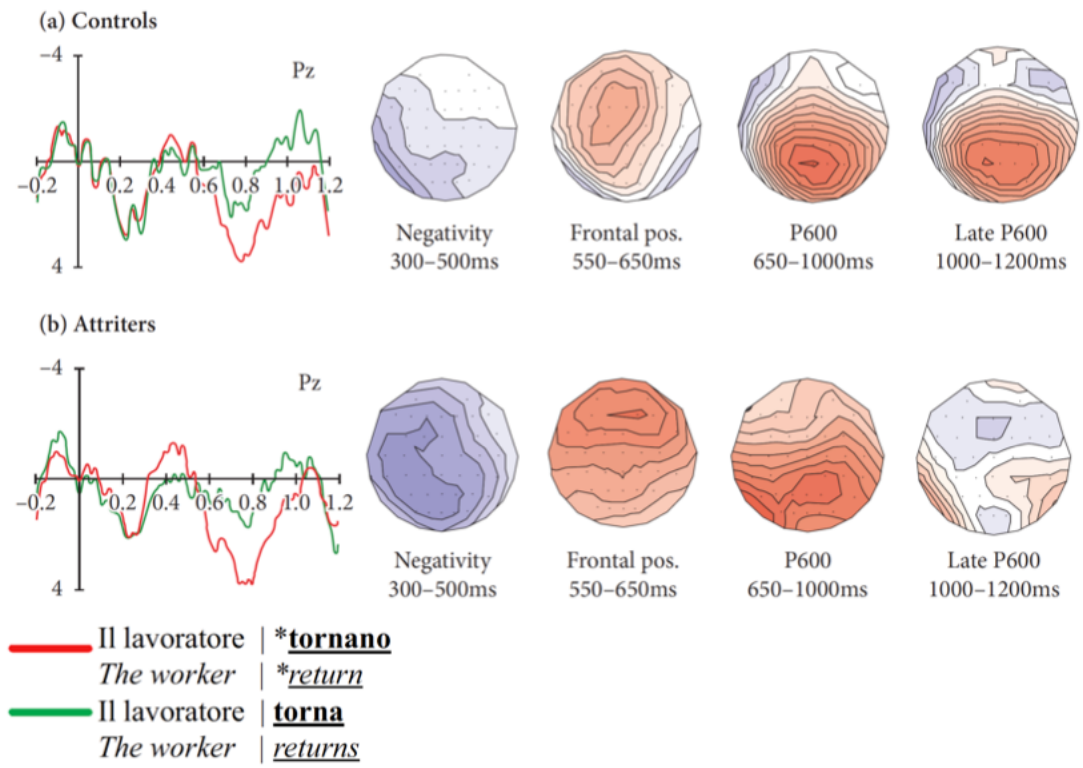

Figure 4, adapted from (176) Figure 3. ERPs elicited by the verb in response to number agreement violations (red) and correct sentences (green) in Controls (a) and Attriters (b). Voltage maps illustrate the scalp distribution of effects observed for time-windows of interest. Controls showed a small left-temporal negativity, followed by a frontal positivity and a posterior P600 lasting until 1,200 ms. Attriters showed a robust N400, a numerically larger frontal positivity and a broadly distributed P600 that was shorter in duration than that of Controls. (Note that, for this contrast, a non-standard baseline interval from -200 to 200 ms was used).

References

1. Wray S, Stockall L, Marantz A (2019) Automatic decomposition revisited with MEG evidence from visual processing of Tagalog circumfixes, infixes, and reduplication. In: Abstracts of the Society for the Neurobiology of Language (SNL). Helsinki, Finland, p https://www.neurolang.org/account/?mtpage=poster_d
2. Gagné CL (2017) Psycholinguistic Approaches to Morphology. In: Aronoff M (ed) Oxford Research Encyclopedia of Linguistics. Oxford Press, Oxford, UK
3. Fiorentino R (2019) Issues in neurolinguistic studies of morphology. In: Aronoff M (ed) Oxford Research Encyclopedia of Linguistics. Oxford Press, Oxford, UK
4. Bloomfield L (1933) Language. Holt, New York, NY
5. Chomsky N (1970) Remarks on nominalization. In: Jacobs R, Rosenbaum P (eds) Redings in English Transformational Grammar. Blaisdell, Waltham: MA
6. Ullman MT, Corkin S, Coppola M, Hickok G, Growdon JH, Koroshetz WJ, Pinker S (1997) A neural dissociation within language: Evidence that the mental dictionary is part of declarative memory, and that grammatical rules are processed by the procedural system. J Cogn Neurosci 9:266–276. doi:10.1162/jocn.1997.9.2.266
7. Taft M, Forster KI (1975) Lexical storage and retrieval of prefixed words. J Verbal Learn Verbal Behav 14:638–647.
8. Taft M, Forster KI (1976) Lexical storage and retrieval of polymorphemic and polysyllabic words. J Verbal Learning Verbal Behav 15:607–620. doi:10.1016/0022-5371(76)90054-2
9. Colé P, Beauvillain C, Segui J (1989) On the representation and processing of prefixed and suffixed derived Words: A differential frequency effect. J Mem Lang 28:1–13. doi:10.1016/0749-596X(89)90025-9
10. Pinker S, Prince A (1992) Regular and irregular morphology and the psychological status of rules of grammar. In: Sutton LA, Johnson C, Shields R (eds) Proceedings of the 17th annual meeting of the Berkeley linguistics society: General session and parasession on the grammar of event structure. Berkeley Linguistics Society, Berkeley, CA, pp 230–251
11. Marcus G, Brinkmann U, Clahsen H, Wiese R, Pinker S (1995) German inflection: The exception that proves the rule. Cogn Psychol 29:189–256. doi:10.1006/cogp.1995.1015
12. Caramazza A, Laudanna A, Romani C (1988) Lexical access and inflectional morphology. Cognition 28:297–332. doi:10.1016/0010-0277(88)90017-0
13. Niemi J, Laine M, Tuominen J (1994) Cognitive morphology in Finnish: foundations of a new model. Lang Cogn Process 9:423–446. doi:10.1080/01690969408402126
14. Frauenfelder U, Schreuder R (1992) Constraining psycholinguistic models of morphological processing and representation: The role of productivity. In: Booij G, van Merle J (eds) Yearbook of Morphology 1991. Kluwer, Dordrecht, pp 165–183
15. Schreuder R, Baayen RH (1995) Modeling morphological processing. In: Feldman LB (ed) Morphological aspects of language processing. Lawrence Erlbaum, Hillsdale, NJ, pp 131–154
16. Matushansky O, Marantz A (2013) Distributed morphology today. MIT Press, Cambridge, MA
17. Bybee J (1995) Regular morphology and the lexicon. Lang Cogn Process 10:425–455. doi:10.1080/01690969508407111
18. Butterworth B (1983) Lexical representation. In: Butterworth B (ed) Language Production. Academic Press, London, pp 257–294
19. Seidenberg MS, McClelland JL (1989) A distributed, developmental model of word recognition and naming. Psychol Rev 96:523–568. doi:10.1037//0033-295X.96.4.523

20. Devlin JT, Jamison HL, Matthews PM, Gonnerman LM (2004) Morphology and the internal structure of words. Proc Natl Acad Sci 101:14984–14988. doi:10.1073/pnas.0403766101
21. Lukatela G, Gligorijevic B, Kostic A, Turvey MT (1980) Representation of inflected nouns in the internal lexicon. Mem Cogn 8:415–423. doi:10.3758/BF03211138
22. Leminen A, Smolka E, Duñabeitia JA, Pliatsikas C (2018) Morphological processing in the brain: the good (inflection), the bad (derivation) and the ugly (compounding). Cortex. https://doi.org/10.1016/j.cortex.2018.08.016.
23. Grainger J, Holcomb PJ (2009) Watching the word go by: on the timecourse of component processes in visual word recognition. Lang Linguist Compass 3:128–156. doi:10.1111/j.1749-818X.2008.00121.x
24. Kutas M, Hillyard SA (1980) Reading senseless sentences: Brain potentials reflect semantic incongruity. Science 207:203–205. doi:10.1126/science.7350657
25. Kutas M, Hillyard SA (1983) Event-related brain potentials to grammatical errors and semantic anomalies. Mem Cognit 11:539–550. doi:10.3758/BF03196991
26. Kutas M, Lindamood TE, Hillyard SA (1984) Word expectancy and event-related brain potentials during sentence processing. In: Kornblum S, Requin J (eds) Preparatory States and Processes. Lawrence Erlbaum, Hillsdale, New Jersey, pp 217–237
27. Jescheniak JD, Hahne A, Schriefers H (2003) Information flow in the mental lexicon during speech planning: evidence from event-related brain potentials. Cogn Brain Res 15:261–276. doi:10.1016/S0926-6410(02)00198-2
28. Wang M, Chen Y, Schiller NO (2019) Lexico-syntactic features are activated but not selected in bare noun production: Electrophysiological evidence from overt picture naming. Cortex 116:294–307. doi:10.1016/j.cortex.2018.05.014
29. Ganushchak L, Christoffels I, Schiller NO (2011) The use of electroencephalography in language production research: A review. Front Psychol 2:208. doi:10.3389/fpsyg.2011.00208
30. Kutas M, Federmeier KD (2011) Thirty years and counting: Finding meaning in the N400 component of the event-related brain potential (ERP). Annu Rev Psychol 62:621–647. doi:10.1146/annurev.psych.093008.131123
31. Amenta S, Crepaldi D (2012) Morphological processing as we know it: an analytical review of morphological effects in visual word identification. Front Psychol 3:232. doi:10.3389/fpsyg.2012.00232
32. Helenius P, Salmelin R, Service E, Connolly JF (1999) Semantic cortical activation in dyslexic readers. J Cogn Neurosci 11:535–550. doi:10.1162/089892999563599
33. Pylkkänen L, Feintuch S, Hopkins E, Marantz A (2004) Neural correlates of the effects of morphological family frequency and family size: An MEG study. Cognition 91:B35–45. doi:10.1016/j.cognition.2003.09.008
34. Beretta A, Fiorentino R, Poeppel D (2005) The effects of homonymy and polysemy in lexical access: An MEG study. Cogn Brain Res 24:57– 65. doi:10.1016/j.cogbrainres.2004.12.006
35. Mondini S, Jarema G, Luzzatti C, Burani C, Semenza C (2002) Why is “Red Cross” different from “Yellow Cross”?: A neuropsychological study of noun–adjective agreement within Italian compounds. Brain Lang 81:621–634. doi:10.1006/brln.2001.2552
36. Leminen A, Leminen M, Lehtonen M, Nevalainen P, Ylinen S, Kimppa L, Sannemann C, Mäkelä JP, Kujala T (2011) Spatiotemporal dynamics of the processing of spoken inflected and derived words: A combined EEG and MEG study. Front Hum Neurosci 5:66.

doi:doi:10.3389/fnhum.2011.00066
37. Leminen A, Kujala T, Shtyrov Y (2013) Neural dynamics of inflectional and derivational morphology processing in the human brain. Cortex 2758:e2771. doi:10.1016/j.cortex.2013.08.007
38. Beyersmann E, Bolger D, Pattamadilok C, New B, Grainger J, Ziegler JC (2019) Morphological processing without semantics: An ERP study with spoken words. Cortex 116:55–73. doi:10.1016/j.cortex.2019.02.008
39. Whiting CM, Marslen-Wilson WD, Shtyrov Y (2013) Neural dynamics of inflectional and derivational processing in spoken word comprehension: laterality and automaticity. Front Hum Neurosci 7:759. doi:10.3389/fnhum.2013.00759
40. Solomyak O, Marantz A (2010) Evidence for early morphological decomposition in visual word recognition. J Cogn Neurosci 22:2042–2057. doi:10.1162/jocn.2009.21296
41. Gwilliams L, Marantz A (2018) Morphological representations are extrapolated from morphosyntactic rules. Neuropsychologia 114:77–87. doi:10.1016/j.neuropsychologia.2018.04.015
42. Fiorentino R, Poeppel D (2007) Compound words and structure in the lexicon. Lang Cogn Process 22:953–1000. doi:10.1080/01690960701190215
43. Fiorentino R, Naito-Billen Y, Bost J, Fund-Reznicek E (2014) Electrophysiological evidence for the morpheme- based combinatoric processing of English compounds. Cogn Neuropsychol 31:123–146. doi:10.1080/02643294.2013.855633
44. El Yagoubi R, Chiarelli V, Mondini S, Perrone G, Danieli M, Semenza C (2008) Neural correlates of Italian nominal compounds and potential impact of headedness effect: An ERP study. Cogn Neuropsychol 25:559–581. doi:10.1080/02643290801900941
45. Stites MC, Federmeier KD, Christianson K (2016) Do morphemes matter when reading compound words with transposed letters? Evidence from eye-tracking and event-related potentials. Lang Cogn Neurosci 31:1299–1319. doi:10.1080/23273798.2016.1212082
46. Leinonen A, Brattico P, Jarvenpaa M, Krause CM (2008) Event-related potential (ERP) responses to violations of inflectional and derivational rules of Finnish. Brain Res 1218:181–193. doi:10.1016/j.brainres.2008.04.049
47. Bölte J, Jansma BM, Zilverstand A, Zwitserlood P (2009) Derivational morphology approached with event-related potentials. Ment Lex 4:336–353. doi:10.1075/ml.4.3.02bol
48. Leminen A, Leminen M, Krause CM (2010) Time course of the neural processing of spoken derived words: an event-related potential study. Neuroreport 21:948–952. doi:10.1097/WNR.0b013e32833e4b90
49. Bölte J, Schulz C, Dobel C (2010) Processing of existing, synonymous, and anomalous German derived adjectives: An MEG study. Neurosci Lett 469:107–111. doi:10.1016/j.neulet.2009.11.054
50. Neophytou K, Manouilidou C, Stockall L, Marantz A (2018) Syntactic and semantic restriction son morphological recomposition: MEG evidence from Greek. Brain Lang 183:11–20. doi:10.1016/j.bandl.2018.05.003
51. Stockall L, Manouilidou C, Gwilliams L, Neophytou K, Marantz A (2019) Prefix stripping re-re-revisited: MEG investigations of morphological decomposition and recomposition. Front Psychol 10:1964. doi:10.3389/fpsyg.2019.01964
52. Clahsen H (1999) Lexical entries and rules of language: A multidisciplinary study of German inflection. Behav Brain Sci 22:991–1060. doi:10.1017/S0140525X99002228
53. Lehtonen M, Cunillera T, Rodríguez-Fornells A, Hulténa A, Tuomainen J, Lainew M (2007) Recognition of morphologically complex words in Finnish: Evidence from event-

related potentials. Brain Res 1148:123–137. doi:10.1016/j.brainres.2007.02.026
54. Leinonen A, Gronholm-Nyman P, Jarvenpaa M, Soderholm C, Lappi O, Laine M, Krause CM (2009) Neurocognitive processing of auditorily and visually presented inflected words and pseudowords: evidence from a morphologically rich language. Brain Res 1275:54–66. doi:10.1016/j.brainres.2009.03.057
55. Domínguez A, de Vega M, Barber H (2004) Event-related brain potentials elicited by morphological, homographic, orthographic, and semantic priming. J Cogn Neurosci 16:598–608. doi:10.1162/089892904323057326
56. Royle P, Drury JE, Bourguignon N, Steinhauer K (2012) The temporal dynamics of inflected word recognition: A masked ERP priming study of French verbs. Neuropsychologia 50:3542–3553. doi:10.1016/j.neuropsychologia.2012.09.007
57. Kastner I, Pylkkänen L, Marantz A (2018) The form of morphemes: MEG evidence from masked priming of two Hebrew templates. Front Psychol 9:2163. doi:10.3389/fpsyg.2018.02163
58. Martin CD, Thierry G (2008) Interplay of orthography and semantics in reading: an event-related potential study. Neuroreport 19:1501–1505. doi:10.1097/WNR.0b013e328310108c
59. Beyersmann E, Iakimova G, Ziegler JC, Colé P (2014) Semantic processing during morphological priming: An ERP study. Brain Res 1579:45–55. doi:10.1016/j.brainres.2014.07.010
60. Cavalli E, Colé P, Badier J-M, Ziegler JC (2016) Spatiotemporal dynamics of morphological processing in visual word recognition. J Cogn Neurosci 28:1228–1242. doi:10.1162/jocn_a_00959
61. Whiting CM, Shtyrov Y, Marslen-Wilson WD (2014) Real-time functional architecture of visual word recognition. J Cogn Neurosci 27:246–265. doi:10.1162/jocn_a_00699
62. Leminen A, Lehtonen M, Leminen M, Nevalainen P, Mäkelä JP, Kujala T (2013) The role of attention in processing morphologically complex spoken words: an EEG/MEG study. Front Hum Neurosci 6:353. doi:doi.org/10.3389/fnhum.2012.00353
63. Bertram R (2000) Morphology in the mind. Turku University Library, Turku, Finland
64. Fruchter J, Marantz A (2015) Decomposition, lookup, and recombination: MEG evidence for the full decomposition model of complex visual word recognition. Brain Lang 143:81–96. doi:10.1016/j.bandl.2015.03.001
65. Prins T, Dijkstra T, Koeneman O (2019) How Dutch and Turkish-Dutch readers process morphologically complex words: An ERP study. J Neurolinguistics 50:37–52. doi:10.1016/j.jneuroling.2017.12.003
66. Dressler WU (1997) On productivity and potentiality in inflectional morphology. In: CLASNET Working Papers. Montreal, pp 1–22
67. Baayen RH (1994) Productivity in language production. Lang Cogn Process 9:447–469. doi:10.1080/01690969408402127
68. Baayen RH (1993) On frequency, transparency and productivity. In: Booij GE, van Marle J (eds) Yearbook of Morphology 1992. Kluwer, Dordrecht, pp 181–208
69. Koester D, Gunter TC, Wagner S (2007) The morphosyntactic decomposition and semantic composition of German compound words investigated by ERPs. Brain Lang 102:64–79. doi:10.1016/j.bandl.2006.09.003
70. Holle H, Gunter TC, Koester D (2010) The time course of lexical access in morphologically complex words. Neuroreport 21:319–323. doi:10.1097/WNR.0b013e328335b3e0
71. Koester D, Schiller NO (2008) Morphological priming in overt language production:

Electrophysiological evidence from Dutch. Neuroimage 42:1622–1630. doi:10.1016/j.neurimage.2008.06.043
72. Brooks TL, Cid de Garcia D (2015) Evidence for morphological composition in compound words using MEG. Frontiers in Human Neuroscience. Front Hum Neurosci 9:215. doi:10.3389/fnhum.2015.00215
73. Davis CP, Libben G, Segalowitz SJ (2019) Compounding matters: Event-related potential evidence for early semantic access to compound words. Cognition 184:44–52. doi:10.1016/j.cognition.2018.12.006
74. Vergara-Martínez M, Duñabeitia JA, Laka I, Carreiras M (2009) ERP correlates of inhibitory and facilitative effects of constituent frequency in compound word reading. Brain Res 1257:53–64. doi:10.1016/j.brainres.2008.12.040
75. Duñabeitia JA, Perea M, Carreiras M (2007) The role of the frequency of constituents in compound words: Evidence from Basque and Spanish. Psychon Bull Rev 14:1171–1176. doi:doi.org/10.3758/BF03193108
76. Wang W, Lu A, He D, Zhang B, Zhang JX (2017) ERP evidence for chinese compound word recognition: Does morpheme work all the time? NeuroQuantology 5:142–152. doi:10.14704/nq.2017.15.3.1105
77. Arcara G, Marelli M, Buodo G, Mondini S (2014) Compound headedness in the mental lexicon: An event-related potential study. Cogn Neuropsychol 31:164–83. doi:10.1080/02643294.2013.847076
78. Lavric A, Clapp A, Rastle K (2007) ERP evidence of morphological analysis from orthography: A masked priming study. J Cogn Neurosci 19:866–877. doi:10.1162/jocn.2007.19.5.866
79. Morris J, Frank T, Grainger J, Holcomb PJ (2007) Semantic transparency and masked morphological priming: An ERP investigation. Psychophysiology 44:506–521. doi:10.1111/j.1469-8986.2007.00538.x
80. Morris J, Grainger J, Holcomb PJ (2008) An electrophysiological investigation of early effects of masked morphological priming. Lang Cogn Process 23:1021–1056. doi:10.1080/01690960802299386
81. Holcomb PJ, Grainger J (2009) ERP effects of short interval masked associative and repetition priming. J Neurolinguistics 22:301–312. doi:10.1016/j.jneuroling.2008.06.004
82. Lau EF, Holcomb PJ, Kuperberg GR (2013) Dissociating N400 effects of prediction from association in single word contexts. J Cogn Neurosci 25:484–502. doi:10.1162/jocn_a_00328
83. Steinhauer K, Royle P, Drury JE, Fromont LA (2017) The priming of priming: Evidence that the N400 reflects context dependent post-retrieval word integration in working memory. Neurosci Lett 651:192–197. doi:https://doi.org/10.1016/j.neulet.2017.05.007
84. Lehtonen M, Monahan PJ, Poeppel D (2011) Evidence for early morphological decomposition: Combining masked priming with magnetoencephalography. J Cogn Neurosci 23:3366–3379. doi:10.1162/jocn_a_00035
85. Lewis G, Solomyak O, Marantz A (2011) The neural basis of obligatory decomposition of suffixed words. Brain Lang 118:118–127. doi:10.1016/j.bandl.2011.04.004
86. Zweig E, Pylkkänen L (2009) A visual M170 effect of morphological complexity. Lang Cogn Process 24:412–439. doi:10.1080/01690960802180420
87. Albright A (2002) Islands of reliability for regular morphology: Evidence from Italian. Language (Baltim) 788:684–709. doi:10.1353/lan.2003.0002
88. Weyerts H, Münte TF, Smid HGOM, Heinze H (1996) Mental representations of

morphologically complex words: an event-related potential study with adult humans. Neurosci Lett 206:125–128. doi:10.1016/S0304-3940(96)12442-3
89. Münte TF, Say T, Clahsen H, Schiltz K, Kutas M (1999) Decomposition of morphologically complex words in English: Evidence from event-related brain potentials. Cogn Brain Res 7:241–253. doi:10.1016/S0926-6410(98)00028-7
90. Rodriguez-Fornells A, Münte TF, Clahsen H (2002) Morphological priming in Spanish verb forms: An ERP repetition priming study. J Cogn Neurosci 14:443–454. doi:10.1162/089892902317361958
91. Lavric A, Pizzagalli D, Forstmeier S, Rippon G (2001) A double dissociation of regular and irregular English past-tense production revealed by event-related potentials and low resolution electromagnetic tomography (LORETA). Clin Neurophysiol 112:1833–1849. doi:10.1016/S1388-2457(01)00615-0
92. Penke M, Weyerts H, Zander E, Münte TF, Clahsen H (1997) How the brain processes complex words: an event-related potential study of German verb inflections. Cogn Brain Res 6:37–52. doi:10.1016/S0926-6410(97)00012-8
93. Bartke S, Rösler F, Streb J, Wiese R (2005) An ERP-study of German "irregular" morphology. J Neurolinguistics 18:29–55. doi:10.1016/j.jneuroling.2004.10.001
94. Weyerts H, Penke M, Dohrn U, Clahsen H, Münte TF (1997) Brain potentials indicate differences between regular and irregular German plurals. Neuroreport 8:957–962. doi:10.1097/00001756-199703030-00028
95. Regel S, Opitz A, Müller G, Friederici AD (2019) Processing inflectional morphology: ERP evidence for decomposition of complex words according to the affix structure. Cortex 116:143–153. doi:10.1016/j.cortex.2018.10.003
96. Müller G (2007) Extended exponence by enrichment: Argument encoding in German, Archi, and Timucua. In: Scheffler T, Tauberer J, Eilam A (eds) Proceedings of the The 30th Annual Penn Linguistics Colloquium. pp 253–266
97. Stockall L, Marantz A (2006) A single route, full decomposition model of morphological complexity: MEG evidence. Ment Lex J 1:85–123. doi:10.1075/ml.1.1.07sto
98. Fruchter J, Stockall L, Marantz A (2013) MEG masked priming evidence for form-based decomposition of irregular verbs. Front Hum Neurosci 7:798. doi:10.3389/fnhum.2013.00798
99. Albright A, Hayes B (2003) Rules vs. analogy in English past tenses: A computational/experimental study. Cognition 90:119–161. doi:10.1016/S0010-0277(03)00146-X
100. Justus T, Larsen J, deMornay Davies P, Swick D (2008) Interpreting dissociations between regular and irregular past-tense morphology: evidence from event-related potentials. Cogn Affect Behav Neurosci 8:178–194. doi:10.3758/CABN.8.2.178
101. Justus T, Yang J, Larsen J, de Mornay Davies P, Swick D (2009) An event-related potential study of cross-modal morphological and phonological priming. J Neurolinguistics 22:584–604. doi:10.1016/j.jneuroling.2009.07.001
102. Bick AS, Frost R, Goelman G (2010) Imaging implicit morphological processing: evidence from Hebrew. J Cogn Neurosci 22:1955–1969. doi:10.1162/jocn.2009.21357
103. Bick AS, Goelman G, Frost R (2008) Neural correlates of morphological processes in Hebrew. J Cogn Neurosci 20:406–420. doi:10.1162/jocn.2008.20028
104. Tsapkini K, Kehayia E, Jarema G (1999) Does phonological change play a role in the recognition of derived forms across modalities? Brain Lang 68:318–323. doi:10.1006/brln.1999.2113

105. Bozic M, Tyler LK, Su L, Wingfield C, Marslen-Wilson WD (2013) Neurobiological systems for lexical representation and analysis in English. J Cogn Neurosci 25:1678–1691. doi:10.1162/jocn_a_00420
106. Bozic M, Szlachta Z, Marslen-Wilson WD (2013) Cross-linguistic parallels in processing derivational morphology: Evidence from Polish. Brain Lang 127:533–538. doi:10.1016/j.bandl.2013.09.001
107. Klimovich-Gray A, Bozic M, Marslen-Wilson WD (2017) Domain-specific and domain general processing in left perisylvian cortex: Evidence from Russian. J Cogn Neurosci 29:382–397. doi:10.1162/jocn_a_01047
108. Marangolo P, Piras F, Galati G, Burani C (2006) Functional anatomy of derivational morphology. Cortex 42:1093–1106. doi:10.1016/S0010-9452(08)70221-1
109. Vannest J, Polk TA, Lewis RL (2005) Dual-route processing of complex words: New fMRI evidence from derivational suffixation. Cogn Affect Behav Neurosci 5:67–76. doi:10.3758/CABN.5.1.67
110. Vannest J, Newport EL, Newman AJ, Bavelier D (2011) Interplay between morphology and frequency in lexical access: The case of the base frequency effect. Brain Res 1373:144–159. doi:10.1016/j.brainres.2010.12.022
111. Luck SJ (2014) An Introduction to the Event-Related Potential Technique, 2nd ed. MIT Press, Cambridge, MA
112. Kandylaki KD, Bornkessel-Schlesewsky I (2019) From story comprehension to the neurobiology of language. Lang Cogn Neurosci 34:405-410. doi:10.1080/23273798.2019.1584679.
113. Hagoort P, Brown CM (1999) Gender electrified: ERP evidence on the syntactic nature of gender processing. J Psycholinguist Res 28:715–728. doi:10.1023/A:1023277213129
114. Gunter TC, Friederici AD, Schriefers H (2000) Syntactic gender and semantic expectancy: ERPs reveal early autonomy and late interaction. J Cogn Neurosci 12:556–568. doi:10.1162/089892900562336
115. Molinaro N, Barber HA, Carreiras M (2011) Grammatical agreement processing in reading: ERP findings and future directions. Cortex 48:908–930. doi:10.1016/j.cortex.2011.02.019
116. Royle P, Drury JE, Steinhauer K (2013) ERPs and task effects in the auditory processing of gender agreement and semantics in French. Ment Lex Spec issue Neural Correl Lex Process 8:216–244. doi:10.1075/ml.8.2.05roy
117. Osterhout L, Mobley LA (1995) Event-related brain potentials elicited by failure to agree. J Mem Lang 24:739–773. doi:10.1006/jmla.1995.1033
118. Hasting AS, Kotz S (2008) Speeding up syntax: On the relative timing and automaticity of local phrase structure and morphosyntactic processing as reflected in event-related brain potentials. J Cogn Neurosci 20:1207–1219. doi:10.1162/jocn.2008.20083
119. Allen M, Badecker W, Osterhout L (2003) Morphological analysis in sentence processing: An ERP study. Lang Cogn Process 18:405–430. doi:10.1080/01690960244000054
120. Newman AJ, Ullman MT, Pancheva R, Waligura DL, Neville HJ (2007) An ERP study of regular and irregular English past tense inflection. Neuroimage 34:435–445. doi:10.1016/j.neuroimage.2006.09.007
121. Morris J, Holcomb PJ (2005) Event-related potentials to violations of inflectional verb morphology in English. Cogn Brain Res 25:963–981. doi:10.1016/j.cogbrainres.2005.09.021
122. Linares RE, Rodriguez-Fornells A, Clahsen H (2006) Stem allomorphy in the Spanish

mental lexicon: evidence from behavioral and ERP experiments. Brain Lang 97:110–120. doi:10.1016/j.bandl.2005.08.008
123. Leminen A, Jakonen S, Leminen M, Mäakelä JP, Lehtonen M (2016) Neural mechanisms underlying word- and phrase-level morphological parsing. J Neurolinguistics 38:26–41. doi:10.1016/j.jneuroling.2015.10.003
124. Hagoort PJ, Brown C, Groothusen J (1993) The syntactic positive shift (SPS) as an ERP measure of syntactic processing. Lang Cogn Process 8:439–483. doi:10.1080/01690969308407585
125. Cantiani C, Lorusso ML, Guasti MT, Sabisch B, Männel C (2013) Characterizing the morphosyntactic processing deficit and its relationship to phonology in developmental dyslexia. Neuropsychologia 51:1595–1607. doi:10.1016/j.neuropsychologia.2013.04.009
126. Coulson S, King JW, Kutas M (1998) Expect the unexpected: Event-related brain response to morphosyntactic violations. Lang Cogn Process 13:21–58. doi:10.1080/016909698386582
127. Hahne A, Friederici AD (1999) Electrophysiological evidence for two steps in syntactic analysis. Early automatic and late controlled processes. J Cogn Neurosci 11:194–205. doi:10.1162/089892999563328
128. Donchin E, Coles MGH (1988) Is the P300 component a manifestation of context updating? Beahvioral Brain Sci 11:357–374. doi:10.1017/S0140525X00058027
129. Alemán Bañón J, Rothman J (2019) Being a participant matters: Event-related potentials show that markedness modulates person agreement in Spanish. Front Psychol 10:746. doi:10.3389/fpsyg.2019.00746
130. Courteau É, Martignetti L, Royle P, Steinhauer K (2019) Eliciting ERP components of morphosyntactic agreement mismatches in perfectly grammatical sentences. Front Psychol 10:1152. doi:10.3389/fpsyg.2019.01152
131. Isel F, Kail M (2018) Morphosyntactic integration in French sentence processing: Event-related brain potentials evidence. J Neurolinguistics 46:23–36. doi:10.1016/j.jneuroling.2017.12.006
132. Tanner D, Morgan-Short K, Luck SJ (2015) How inappropriate high-pass filters can produce artifactual effects and incorrect conclusions in ERP studies of language and cognition. Psychophysiology 52:997–1009. doi:10.1111/psyp.12437
133. Kutas M, Hillyard SA (1984) Brain potentials during reading reflect word expectancy and semantic association. Nature 307:161–163. doi:10.1038/307161a0
134. Deutsch A, Bentin S (2001) Syntactic and semantic factors in processing gender agreement in Hebrew: Evidence from ERPs and eye movements. J Mem Lang 45:220–224. doi:10.1006/jmla.2000.2768
135. Steinhauer K, Drury JE (2012) On the early left-anterior negativity (ELAN) in syntax studies. Brain Lang 120:135–162. doi:doi.org/10.1016/j.bandl.2011.07.001
136. Barber H, Carreiras M (2005) Grammatical gender and number agreement in Spanish: An ERP comparison. J Cogn Neurosci 17:137–153. doi:10.1162/0898929052880101
137. Wicha NYY, Bates EA, Moreno EM, Kutas M (2003) Potato not pope: Human brain potentials to gender expectation and agreement in spanish spoken sentences. Neurosci Lett 346:165–168. doi:10.1016/S0304-3940(03)00599-8
138. Wicha NYY, Moreno EM, Kutas M (2004) Anticipating words and their gender: An event-related brain potential study of semantic integration, gender expectancy and gender agreement in Spanish sentence reading. J Cogn Neurosci 16:1272–1288. doi:10.1162/0898929041920487

139. Guajardo LF, Wicha NYY (2014) Morphosyntax can modulate the N400 component: event related potentials to gender-marked post-nominal adjectives. Neuroimage 91:262–272. doi:10.1016/j.neuroimage.2013.09.077
140. Steinhauer K (2014) Event-related potentials (ERPs) in second language research: A brief introduction to the technique, a selected review, and an invitation to reconsider critical periods in L2. Appl Linguist 4:393–417. doi:10.1093/applin/amu028
141. Royle P, Courteau E (2014) Language processing in children with specific language impairment: a review of event-related potential studies. In: Klein LT, Amato V (eds) Language Processing: New Research. Nova Science Publishers, Hauppauge, NY, pp 33–64
142. Budd M-J, Paulmann S, Barry C, Clahsen H (2015) Producing morphologically complex words: An ERP study with children and adults. Dev Cogn Neurosci 12:51–60. doi:10.1016/j.dcn.2014.11.002
143. Tong X, Chung KKH, McBride C (2014) Two-character chinese compound word processing in Chinese children with and without dyslexia: ERP evidence. Dev Neuropsychol 39:285–301. doi:10.1080/87565641.2014.907720
144. Cantiani C, Lorusso ML, Perego P, Molteni M, Guasti MT (2015) Developmental dyslexia with and without language impairment: ERPs reveal qualitative differences in morphosyntactic processing. Dev Neuropsychol 40:291–312. doi:10.1080/87565641.2015.1072536
145. Cantiani C, Lorusso ML, Perego P, Molteni M, Guasti MT (2013) Event-related potentials reveal anomalous morphosyntactic processing in developmental dyslexia. Appl Psycholinguist 34:1135–1162. doi:10.1017/S0142716412000185
146. Dube S, Kung C, Peter V, Brock J, Demuth K (2016) Effects of type of agreement violation and utterance position on the auditory processing of subject-verb agreement: An ERP study. Front Psychol Lang Sci 7:1276. doi:10.3389/fpsyg.2016.01276
147. Dube S, Kung C, Brock J, Demuth K (2017) Perceptual salience and the processing of subject-verb agreement in 9–11-year-old English-speaking children: Evidence from ERPs. Lang Acquis 26:73–96. doi:10.1080/10489223.2017.1394305
148. Purdy JD, Leonard LB, Weber-Fox C, Kaganovicha N (2014) Decreased sensitivity to long-distance dependencies in children with a history of specific language impairment: Electrophysiological evidence. J Speech, Lang Hear Res 57:1040–1059. doi:10.1044/2014_JSLHR-L-13-0176
149. Haebig E, Weber C, Leonard LB, Deevy P, Tomblin JB (2017) Neural patterns elicited by sentence processing uniquely characterize typical development, SLI recovery, and SLI persistence. J Neurodev Disord 9:22. doi:10.1186/s11689-017-9201-1
150. Weber-Fox C, Leonard LB, Wray AH, Tomblin JB (2010) Electrophysiological correlates of rapid auditory and linguistic processing in adolescents with specific language impairment. Brain Lang 115:162–181. doi:10.1016/j.bandl.2010.09.001
151. Clahsen H, Lück M, Hahne A (2007) How children process over-regularizations: Evidence from event-related brain potentials. J Child Lang 34:601–622. doi:10.1017/S0305000907008082
152. Lück M, Hahne A, Clahsen H (2006) Brain potentials to morphologically complex words during listening. Brain Res 1077:144–152. doi:10.1016/j.brainres.2006.01.030
153. Courteau É, Steinhauer K, Royle P (2015) L'acquisition du groupe nominal en français et de ses aspect morpho-syntaxiques et sémantiques : une étude de potentiels évoqués. Glossa 117:77–93.

154. Gascon A, Lebel V, Royle P, Drury JE, Steinhauer K (2011) Task effects in event related potentials for semantics and gender in French. In: Abstracts of the 10th Symposium of Psycholinguistics. Donostía-San Sebastian, Spain, p 94
155. Royle P, Fromont LA, Courteau E, Steinhauer K (2018) How age and meta-linguistic abilities modulate ERP patterns in French-speaking children. In: Abstracts of the 19th World Congress of Psychophysiology, Lucca, Italy, 4–8 September. p 92
156. Budd M-J, Paulmann S, Barry C, Clahsen H (2013) Brain potentials during language production in children and adults: an ERP study of the English past tense. Brain Lang 127:345–355. doi:10.1016/j.bandl.2012.12.010
157. Jessen A, Fleischhauer E, Clahsen H (2016) Morphological encoding in German children's language production: evidence from event-related brain potentials. J Child Lang 44:427–456. doi:10.1017/S0305000916000118
158. De Cat C, Klepousniotou E, Baayen RH (2015) Representational deficit or processing effect? An electrophysiological study of noun-noun compound processing by very advanced L2 speakers of English. Front Psychol 6:77. doi:10.3389/fpsyg.2015.00077
159. Jessen A, Veríssimo J, Clahsen H (2018) Variability and consistency in late bilinguals' morphology. An ERP production study. Ment Lex 13:186–214. doi:10.1075/ml.18002.jes
160. Kimppa L, Shtyrov Y, Hut SCA, Hedlund L, Leminen M, Leminen A (2019) Acquisition of L2 morphology by adult language learners. Cortex 116:74–90. doi:10.1016/j.cortex.2019.01.012
161. Coughlin CE, Fiorentino R, Royle P, Steinhauer K (2019) Sensitivity to inflectional morphology in a non-native language: Evidence from ERPs. Front Commun 4:21. doi:10.3389/fcomm.2019.00021
162. Hahne A, Müller JL, Clahsen H (2006) Morphological processing in a second language: Behavioral and event-related brain potential evidence for storage and decomposition. J Cogn Neurosci 18:121–134. doi:10.1162/089892906775250067
163. Gillon Dowens M, Vergara M, Barber H (2010) Morphosyntactic processing in late second language learners. J Cogn Neurosci 22:1870–1887. doi:10.1162/jocn.2009.21304
164. Gillon Dowens M, Guo T, Guo J, Barber H, Carreiras M (2011) Gender and number processing in Chinese learners of Spanish—Evidence from event related potentials. Neuropsychologia 49:1651–1659. doi:10.1016/j.neuropsychologia.2011.02.034
165. Carrasco-Ortiz H, Frenck-Mestre C (2014) Phonological and orthographic cues enhance the processing of inflectional morphology. ERP evidence from L1 and L2 French. Front Psychol 5:888. doi:10.3389/fpsyg.2014.00888
166. Frenck-Mestre C, Osterhout L, McLaughlin J, Foucart A (2008) The effect of phonological realization of inflectional morphology on verbal agreement in French: Evidence from ERPs. Acta Psychol (Amst) 128:528–536. doi:10.1016/j.actpsy.2007.12.007
167. Carrasco-Ortiz H, Velázquez A, Jackson-Maldonado D, Avecilla-Ramírez GN, Silva-Pereyra J, Wicha NYY (2017) The role of language similarity in processing second language morphosyntax: Evidence from ERPs. Int J Psychophysiol 117:91–110. doi:10.1016/j.ijpsycho.2017.04.008
168. White EJ, Genesee F, Steinhauer K (2012) Brain responses before and after intensive second language learning: Proficiency based changes and first language background effects in adult learners. PLoS One 7:e52318. doi:PONE-D-12-22453
169. Drury JE, Steinhauer K, Ullman MT (2007) Violating inflectional expectations and morphological (ir)regularity: An ERP study. J Cogn Neurosci Suppl G111:249.
170. Sabourin L, Stowe LA (2003) Second language processing: When are L1 and L2

processed similarly? Second Lang Res 24:397–430. doi:10.1177/0267658308090186
171. Lemhöfer K, Schriefers H, Indefrey P (2014) Idiosyncratic Grammars: Syntactic Processing in Second Language Comprehension Uses Subjective Feature Representations. J Cogn Neurosci 26:1428–1444. doi:10.1162/jocn_a_00609
172. Meulman N, Wieling M, Sprenger SA, Stowe LA, Schmid MS (2015) Age effects in L2 grammar processing as revealed by ERPs and how (not) to study them. PLoS One 10:e0143328. doi:10.1371/journal.pone.0143328
173. Alemán Bañón J, Fiorentino R, Gabriele A (2014) Morphosyntactic processing in advanced second language (L2) learners: An event-related potential investigation of the effects of L1–L2 similarity and structural distance. Second Lang Res 30:275–306. doi:10.1177/0267658313515671
174. Morgan-Short K, Sanz C, Steinhauer K, Ullman MT (2010) Second language acquisition of gender agreement in explicit and implicit training conditions: An event-related potential study. Lang Learn 60:154–193. doi:10.1111/j.1467-9922.2009.00554.x
175. Morgan-Short K, Steinhauer K, Sanz C, Ullman MT (2012) Explicit and implicit second language training differentially affect the achievement of native-like brain activation patterns. J Cogn Neurosci 24:933–947. doi:10.1162/jocn_a_00119
176. Kasparian K, Vespignani F, Steinhauer K (2017) First language attrition induces changes in online morphosyntactic processing and re-analysis: An ERP study of number agreement in complex Italian sentences. Cogn Sci 47:1760–1803. doi:10.1111/cogs.12450
177. Kasparian K, Steinhauer K (2017) When the second language takes the lead: Neurocognitive processing changes in the first language of adult attriters. Front Psychol 8:389. doi:10.3389/fpsyg.2017.00389
178. de Diego Balaguer R, Sebastián-Gallés N, Díaz B, Rodríguez-Fornells A (2005) Morphological processing in early bilinguals: An ERP study of regular and irregular verb processing. Cogn Brain Res 25:312–327. doi:10.1016/j.cogbrainres.2005.06.003
179. Grosjean F (2010) Bilingual: Life and Reality. Harvard University Press, Cambridge, MA
180. Caffarra S, Mendoza M, Davidson D (2019) Is the LAN effect in morphosyntactic processing an ERP artifact? Brain Lang 191:9–16. doi:10.1016/j.bandl.2019.01.003
181. Tanner D (2015) On the left anterior negativity (LAN) in electrophysiological studies of morphosyntactic agreement: a commentary on “grammatical agreement processing in reading: ERP findings and future directions” by Molinaro et al., 2014. Cortex 66:149–155. doi:10.1016/j.cortex.2014.04.007
182. Ullman MT (2001) A Neurocognitive Perspective on Language: The Declarative/Procedural Model. Nat Rev Neurosci 2:717–726. doi:10.1038/35094573
183. Van Petten C, Kutas M (1991) Influences of semantic and syntactic context on open and closed class words. J Mem Cogn 19:95–112. doi:10.3758/bf03198500
184. Fromont LA, Steinhauer K, Royle P (2020) Verbing nouns and nouning verbs: Using a balanced design provides ERP evidence against “syntax-first” approaches to sentence processing. PLOsOne 15:e0229169. doi:10.1371/journal.pone.0229169
185. Henrich J, Heine SJ, Norenzayan A (2010) The weirdest people in the world? Behav Brain Sci 33:61–83. doi:10.1017/S0140525X0999152X
186. Royle P, Steinhauer K, Dessureault E, Herbay A, Brambati S (2019) Aging and language: Maintenance of inflectional morphological representations in older adults. Front Commun 4:16. doi:10.3389/fcomm.2019.00016
187. Drury JE, Mustafawi E, Khwaileh T, Idrissi A (2019) From, meaning and morphology in Arabic masked priming: An ERP study. In: Abstracts of the Society for the Neurobiology

of Language (SNL). Helsinki, Finland, pp 152–3
188. Idrissi A, Muralikrishnan R, Mustafawi E, Khwaileh T, Drury JE (2019) Effects and interactions of orthographic depth and lexicality in Arabic visual word recognition: A lexical decision ERP study. In: Abstracts of the Society for the Neurobiology of Language (SNL). Helsinki, Finland, p 82
189. Ohta S, Oseki Y, Marantz A (2019) Disentangling morphological processing and letter recogntiion: An MEG study of Japanese verbs. In: Abstracts of the Society for the Neurobiology of Language (SNL). Helsinki, Finland, p 237
190. Kuo C-H, Osterhout L (2019) ERP responses to simple vs. complex English morphology in native Mandarin speakers. In: Abstracts of the Society for the Neurobiology of Language (SNL). Helsinki, Finland, p 200
191. Cutler A, Dahan D, Donselaar W van (1997) Prosody in the comprehension of spoken language: A literature review. Lang Speech 40:141–201. doi:10.1177/002383099704000203
192. Koester D (2014) Prosody in parsing morphologically complex words: Neurophysiological evidence. Cogn Neuropsychol 31:147–163. doi:10.1080/02643294.2013.857649
193. Meinzer M, Lahiri A, Flaisch T, Hannemann R, Eulitz C (2009) Opaque for the reader but transparent for the brain: Neural signatures of morphological complexity. Neuropsychologia 47:1964–1971. doi:10.1016/j.neuropsychologia.2009.03.008
194. Pliatsikas C, Wheeldon L, Lahiri A, Hansen PC (2014) Processing of zero-derived words in English: An fMRI investigation. Neuropsychologia 53:47–53. doi:10.1016/j.neuropsychologia.2013.11.003
195. Alegre M, Gordon P (1999) Rule-based versus associative processes in derivational morphology. Brain Lang 68:347–354. doi:10.1006/brln.1999.2066
196. Pollatsek A, Drieghe D, Stockall L, de Almeida RG (2010) The interpretation of ambiguous trimorphemic words in sentence context. Psychon Bull Rev 17:88–94. doi:10.3758/PBR.17.1.88
197. Fromont L, Royle P, Herbay A, Misirliyan C, Steinhauer K (2019) Reevaluating the dynamics of auditory sentence processing: an ERP study in French. In: Abstracts of the Society for the Neurobiology of Language (SNL). Helsinki, Finland, pp 105–106
198. Courteau E, Royle P, Gascon A, Marquis A, Drury JE, Steinhauer K (2013) Gender concord and semantic processing in French children: An auditory ERP study. In: Baiz S, Goldman N, Hawkes R (eds) BUCLD 37 Proceedings. Cascadilla, Sommerville, MA, pp 87–99
199. Pourquié M, Royle P (2013) Neuroimaging and Aphasiology in the XXI Century: EEG and MEG Studies on Language Processing in Aphasia Since the Year 2000. In: Klein LT, Amato V (eds) Language Processing: New Research. Nova Science Publishers, Hauppauge, NY, pp 1–32
200. Rapp B, Caramazza A (2003) Selective deficits with spoken nouns and written verbs: A single case study. J Neurolinguistics 15:373–402. doi:10.1016/S0911-6044(01)00040-9
201. Anshen F, Aronoff M (1988) Producing morphologically complex words. Linguistics 26:641–655. doi:10.1515/ling.1988.26.4.641
202. MacWhinney B (1975) Rules, rote and analogy in morphological formations by Hungarian children. J Child Lang 2:65–77. doi:10.1017/S0305000900000891
203. Connolly JF, Phillips NA (1994) Event-related potential components reflect phonological processing of the terminal word of spoken sentences. J Cogn Neurosci 6:256–266. doi:10.1162/jocn.1994.6.3.256

204. Newman RL, Connolly JF, Service E, McIvor K (2003) Influence of phonological expectations during a phoneme deletion task: Evidence from event-related brain potentials. Psychophysiology 40:640–647. doi:10.1111/1469-8986.00065
205. Moscoso del Prado Martín F, Kostić A, Baayen RH (2004) Putting the bits together: an information theoretical perspective on morphological processing. Cognition 94:1–18. doi:10.1016/j.cognition.2003.10.015
206. Clahsen H, Rothweiler M, Woest A, Marcus GF (1992) Regular and irregular inflection in the acquisition of German noun plurals. Cognition 45:225–255. doi:10.1016/0010-0277(92)90018-D
207. Clahsen H, Aveledo F, Roca I (2002) The development of regular and irregular verb inflection in Spanish child language. J Child Lang 29:591–622. doi:10.1017/S0305000902005172
208. Royle P, Beritognolo G, Bergeron E (2012) Regularity, sub-regularity and irregularity in French acquisition. In: van der Auwera J, Stolz T, Urdze A (eds) Irregularity in Morphology (and Beyond). Akademie Verlag, Berlin, pp 227–250
209. Marslen-Wilson W, Tyler LK, Waksler R, Older L (1994) Morphology and meaning in the English mental lexicon. Psychol Rev 101:3–33. doi:10.1037//0033-295X.101.1.3
210. Desai R, Conant L, Waldron E, Binder JR (2006) FMRI of past tense processing: the effects of phonological complexity and task difficulty. J Cogn Neurosci 18:278–297. doi:10.1162/089892906775783633
211. Jaeger JJ, Lockwood A, Kemmerer D, Van Valin R, Murphy B, Khalak H (1996) A positron emission tomography study of regular and irregular verb morphology in English. Language (Baltim) 72:451–497. doi:10.2307/416276
212. Sach M, Seitz RJ, Indefrey P (2004) Unified inflectional processing of regular and irregular verbs: A PET study. Neuroreport 15:533–537. doi:10.1097/00001756-200403010-00030
213. Indefrey P, Brown C, Hagoort P, Herzog H, Sach M, Seitz R (1997) A PET study of cerebral activation patterns induced by verb inflection. Neuroimage 5:S458. doi:10.1016/S1053-8119(97)80019-5
214. Zou L, Packard JL, Xia Z, Liu Y, Shu H (2016) Neural correlates of morphological processing: Evidence from Chinese. Front Hum Neurosci 9:714. doi:10.3389/fnhum.2015.00714
215. Lehtonen M, Vorobyev VA, Hugdahl K, Tuokkola T, Laine M (2006) Neural correlates of morphological decomposition in a morphologically rich language: An fMRI study. Brain Lang 98:182–193. doi:10.1016/j.bandl.2006.04.011
216. Yokoyama S, Miyamoto T, Riera J, Kim J, Akitsuki Y, Iwata K, Yoshimoto K, Horie K, Sato S, Kawashima R (2006) Cortical mechanisms involved in the processing of verbs: An fMRI study. J Cogn Neurosci 18:1304–1313. doi:10.1162/jocn.2006.18.8.1304
217. Friederici AD, Mecklinger A, Spencer KM, Steinhauer K, Donchin E (2001) Syntactic parsing preferences and their on-line revisions: A spatio-temporal analysis of event-related brain potentials. Cogn Brain Res 11:305–323. doi:10.1016/S0926-6410(00)00065-3
218. Barber H, Carreiras M (2003) Integrating gender and number information in Spanish word pairs: An ERP study. Cortex 39:465–482. doi:doi:10.1016/j.cortex.2011.02.019
219. Franck J, Cronel-Ohayon S, Chillier L, Frauenfelder UH, Hamann C, Rizzi L, Zesiger P (2004) Normal and pathological development of subject-verb agreement in speech production: A study on French children. J Neurolinguistics 17:147–180. doi:10.1016/S0911-6044(03)00057-5

220. Clahsen H, Jessen A (2019) Do bilingual children lag behind? A study of morphological encoding using ERPs. J Child Lang 46:955–979. doi:10.1017/S0305000919000321
221. Lehtonen M, Vorobyev V, Soveri A, Hugdahl K, Tuokkola T, Laine M (2009) Language-specific activations in the brain: Evidence from inflectional processing in bilinguals. J Neurolinguistics 22:495–513. doi:10.1016/j.neuroling.2009.05.001
222. Bick AS, Goelman G, Frost R (2011) Hebrew brain vs. English brain: language modulates the way it is processed. J Cogn Neurosci 23:2280–2290. doi:10.1162/jocn.2010.21583