Title:
The neurolinguistics of the L2 morphological system: the role of grammar-related and speaker-related factors

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Abstract

This chapter provides an overview of the neural correlates related to second language morphological processing, by integrating recent empirical evidence coming from event-related potentials, functional magnetic resonance imaging, and non-invasive brain stimulation. The chapter shows that the processing of morphological information in second language cannot be seen as an encapsulated phenomenon that can be studied without considering both grammar-related (e.g., first language and second language similarity) and speaker-related factors (e.g., second language immersion, age-of-acquisition). Finally, the chapter proposes that the role of traditional concepts such as native-likeness and second language proficiency might be reconsidered in future research.

Introduction and Critical Definitions

Morphemes are the smallest units in language that convey meaning. Inflectional morphemes like *-i* and *-ed* in (1) and (2) below are combined with a stem via affixation to generate different forms of the same lexical item, for example, a verb with different number, person, or tense features.

(1) *Re-í*
stem-affix1.sg.past/'I laughed'
(2) *Laugh-ed*
stem-affix.past

A native or proficient non-native speaker of Spanish will be able to extract a composite set of information from the morpheme *-í* in (1), namely that a single individual laughed at some point in the past and that this is the speaker of the utterance. Conversely, a reader with little knowledge of Spanish may be unable to extract the full set of information provided by the verb.

How is morphological knowledge attained in a second language (L2)? Can it become native-like, and how? We review and critically evaluate recent neuroimaging studies that have addressed these questions, with the goal of highlighting the role that grammar- and speaker-related factors play in shaping the L2 morphological system and its neurocognitive underpinnings. Native-like morphological knowledge refers here to the ability of L2 speakers to process the L2 as efficiently and automatically as their native language. Yet, we clarify that native-likeness does not assume the existence of a monolingual speaker norm and recognizes that L2 speakers can only become bilingual, by definition, given that they already possess the knowledge of one language (their mother tongue).

L2 learning occurs either simultaneously (e.g., in early bilinguals) or sequentially (e.g., in late learners) with respect to the first language (L1). Understanding the (possible) cross-linguistic transfer of rules, and the conditions under which it occurs is thus pivotal to understanding how the L2 language system develops (e.g., MacWhinney, 2005). We refer to this factor as the L1-L2 similarity factor (see Sabourin & Manning, this volume). L1-L2 similarity refers to structurally mappable features, that is, features that are present both in the L1 and in the L2 (MacWhinney, 2005). Morphological features can also be similarly or dissimilarly realized/distributed across constituents in the two languages. The L1 and the L2 are considered similar here if the morphological feature at issue (e.g., number) is present and realized on the same constituents (e.g., noun-verb, adjective-noun) in both languages. However, both aspects of similarity are also considered separately, when possible.

Experience-related factors that pertain to the speakers' L2 history, such as age of acquisition (AoA), proficiency, and immersion in an L2 environment are also considered crucial during learning (e.g., Ullman, 2014, 2020; see Luque & Covey, this volume). AoA refers to the starting point of L2 learning, i.e., when the speaker was first exposed to the language. Proficiency refers to the ability to use a language, as measured by performance on standardized tests or task-related accuracy scores. Immersion duration refers to the length of residence in an L2-speaking population. We review evidence about all these factors, mainly from electroencephalography (EEG/ERPs) and functional magnetic resonance imaging (fMRI), but also briefly from non-invasive brain stimulation (NIBS), and comment on their potential to investigate L2 morphological processing and the brain areas that support it. Because of the few ERP studies available on L2 morphological production, our focus will be primarily on L2 sentence comprehension studies.

Critical Issues and Theoretical Perspectives

Within neurolinguistics, historical, theoretical, and methodological issues exist in defining how L2 morphological knowledge is attained and whether it can reach native-likeness. Historically, early experimental research on L2 processing was mainly conducted in English, a language with an impoverished morphological system. Such findings are therefore difficult to generalize to morphologically richer languages (such as Spanish, Hindi, or Finnish), in which inflection and morphosyntactic relations can include a wider set of features (e.g., gender, person, number, and tense) and constituents (e.g., determiners, adjectives, as well as demonstratives, nouns, and verbs).

Theoretically, models of L2 processing differ in the relevance they attribute to linguistic and experiential factors in L2 processing. Whereas proposals like the competition Model (MacWhinney, 2005, 2018) formalize and discuss how L1-L2 cross-language interaction can affect ultimate L2 attainment, accounts like the declarative/procedural model (Ullman, 2014, 2020; see also Morgan-Short & Ullman, this volume) highlight the importance of experience-related factors such as L2 AoA and immersion.

In this vein, previous reviews and meta-analyses have failed to reach a consensus on the relative weight that grammar- and speaker-related factors have on the native-likeness of L2 morphological processing (e.g., Caffarra et al., 2015, De Diego-Balaguer & Rodriguez-Fornells, 2010; Roncaglia-Denissen & Kotz, 2016; Tanner et al., 2014). L1-L2 similarity has been indicated as a key factor in some analyses (e.g., Kotz, 2009) but less crucial in others (e.g., Caffarra et al., 2015; Polczynska & Bookheimer, 2021). The so-called critical period hypothesis (Birdsong, 2018; Hartshorne et al., 2018; Johnson & Newport, 1989; Newport et al., 2001), and the assumption that the later the L2 is acquired the lower its native-likeness is, gave a prominent role to AoA, although more recent work suggests that this factor may be less crucial than previously considered (e.g., Kotz, 2009; Steinhauer, 2014; see also Caffarra et al., 2015).

In addition to L1-L2 similarity and AoA, proficiency has been indicated as a key factor in determining the temporal dynamics of L2 morphological processing and the degree of neural convergence between L1 and L2 (e.g., Steinhauer et al. 2009; see also Kotz, 2009; Van Hell & Tokowicz, 2010). Yet, this factor has also been considered problematic, due to differences in its measurement across studies and its correlation with other variables such as exposure, AoA, and immersion (Ullman, 2014; for more on AoA and proficiency, see Fromont, this volume). Finally, the learning environment also plays a significant role in L2 final attainment. Immersive contexts have a positive impact on L2 acquisition (for a recent overview see Jackson & Schwiter, 2019) because they provide more naturalistic and variegated exposure to the L2 compared to formal education settings in the L1-speaking country. Longer immersion duration can lead to higher grammatical sensitivity (Caffarra et al., 2015). However, the evidence available is still limited, as few studies have focused on this variable (for more on learning context, see Bowden & Faretta-Stutenberg, this volume).

From a methodological perspective, the available neuroimaging evidence on L2 morphological processing mainly comes from EEG/ERP studies, arguably because this technique is more accessible across laboratories than (more expensive) techniques such as fMRI, or does not have potential side effects, as with NIBS. Combining the experimental evidence from these three different techniques enables the characterization of both the time course and the neural implementation of the mechanisms that subserve L2 morphological processing, as well as the identification of the brain substrates that could be causally involved. This is the approach that we undertake in this review.

Thus, the goals of the current review are to provide an updated picture of the role of grammar- and speaker-related factors based on recent neuroimaging evidence and to identify overlooked aspects that may deepen our insight into the complexity of L2 morphological processing.

Critical Research Outcomes and Current Empirical Knowledge

Event-related Potential (ERP) Studies

ERPs have been widely adopted in L2 research (for more on this method, see Dickson & Pelzl, this volume). ERPs are computed by averaging the portion of the electroencephalogram (EEG) signal that is time-locked to the presentation of a relevant stimulus (e.g., an isolated word, or a word in a sentence). The main advantages of ERP data are the ability to record neural activity continuously, without time delay, and with a high temporal resolution (in the millisecond range).

Sentence comprehension ERP studies offer a comprehensive picture of the role of grammar- and speaker-related factors during L2 morphosyntactic processing. Sentences are generally presented visually word-by-word at the center of the screen at a fixed pace, and the participant is required to provide a grammaticality judgment at the end of each sentence. The electrophysiological activity generated by a word containing a grammatical error (e.g., **My cat <u>are</u> cute*) is then compared with the activity generated by the same word in a grammatical sentence (e.g., *My cats <u>are</u> cute*).

Inflection errors tend to elicit early negativities (250-500 ms after stimulus presentation), followed by a late positivity peaking about 600 ms post-stimulus onset. An early negativity with anterior and left-lateralized topography is referred to as left-anterior negativity (LAN), as opposed to the more broadly distributed negativity that characterizes the N400 effect. These negativities are thought to reflect automatic morphosyntactic processing (see Molinaro et al., 2011 for a review) and semantic/lexical integration difficulties (see Lau et al., 2008 for a review). Whereas these early negativities are not consistently reported across studies and languages, late positive-going deflections represent a rather stable correlate of morpho-syntactic anomalies. They are typically evident in central-posterior areas of the scalp and are often referred to as a 'P600'. Functionally, P600 effects are generally interpreted as an index of structure integration or reanalysis (see Molinaro et al., 2011 for a review).

The emergence of early negative and late positive effects has been used to delineate different stages in the development of L2 morphosyntactic knowledge (e.g., Osterhout et al., 2004; Osterhout et al., 2006; Steinauer et al., 2009). When the speaker has very little knowledge of the L2 grammar, no ERP effects arise when comparing grammatically correct and incorrect sentences because the speaker cannot detect the grammatical error. Subsequently, the speaker may start memorizing salient word/morphological combinations (e.g., *My cats are*…) as unanalyzed chunks. At this stage, any violation of the memorized pattern (e.g., **My cat are*…) would result as unfamiliar, thus triggering an N400, which is highly sensitive to word sequence probabilities. Finally, when L2 proficiency is attained, the speaker is able to abstract morphosyntactic rules successfully, and consequently shows native-like ERP patterns in response to violations, i.e., left-anterior or bilateral early negativities followed by a P600. In these accounts, different stages of morphosyntactic acquisition are mainly driven by L2 proficiency.

However, in their meta-analysis, Caffarra et al. (2015) found that other factors may play a role. Immersion duration had an impact on early ERP responses and their underlying cognitive mechanisms: The probability of reporting a LAN effect was higher when the immersion in an L2-speaking country was long (> 5 years). Conversely, proficiency had an impact on late mechanisms of (morpho)syntactic processing: More P600 effects were found when L2 proficiency was high (above 75%). Interestingly, AoA only marginally affected N400 effects, and L1-L2 similarity did not play a crucial role in any ERP effect.

Table 9.1A summarizes ERP violation studies investigating sentence-level comprehension of L2 inflection published after Caffarra et al.'s meta-analysis. Considering these recent studies, it seems that the native-likeness of the ERP patterns changes as a function of several factors, as suggested in previous work and reviewed below.

Grammar-Related Factors

By considering different dimensions of L1-L2 similarity (type of feature, type of relation/configuration), our review of more recent studies suggests that a finer-grained classification of L1-L2 similarity can capture effects (see Alemán Bañón et al., 2017; Díaz et al. 2016; Gabriele et al., 2021; Martinez de la Hidalga et al., 2021) that previous work could not identify, although the evidence still appears somewhat heterogeneous. Gabriele et al. (2021) found similar ERP responses (P600) in response to subject-verb and adjective-noun number violations in L1 English L2 Spanish speakers, thus suggesting that the presence/absence of a feature in the L1 inventory plays a bigger role compared to the morphological realization of this feature across languages. In contrast, Díaz et al. (2016) reported data from Basque suggesting that the way a feature is realized is important. They tested two groups of L1 Spanish L2 Basque speakers with early and later L2 AoA. The violation of a shared feature (number) that is expressed on different constituents in the L2 (object-verb) triggered an N400 in the group of late learners and a marginal P600 in early bilinguals. Native speakers showed P600 effects in response to these violations (Díaz et al. 2011).

Speaker-Related Factors

In contexts where the L2 speakers cannot exploit consolidated L1 grammatical knowledge to process L2 morphology, speaker-related factors seem to become relevant. In a study with L1 Polish/Russian-L2 German speakers, Meulman et al. (2015) showed that morphological similarity may determine the appearance of AoA effects. They found different P600 effects as a function of AoA when processing an L1-L2 dissimilar phenomenon (i.e., determiner-noun gender agreement; see also Nichols & Joanisse, 2019), but not when processing a similar phenomenon (tense/finiteness marking). These findings suggest that when the L1 and the L2 share similar morphological properties, both early and late learners can reach native-like processing. Conversely, when the L1 and the L2 differ morphologically, native-like processing may be attained only if the L2 is acquired earlier in life.

Similarly, L2 proficiency has been shown to interact with L1-L2 similarity. For example, Alemán Bañón et al. (2018) and Gabriele et al. (2021) investigated similarity effects with L1 English speakers of L2 Spanish. When the morphological patterns differed (e.g., gender, which is not morphologically realized in adjective-noun relations in English), only highly proficient speakers of Spanish showed P600 effects. When a feature present in both languages was manipulated (number), both low and high-proficiency speakers showed P600 effects.

Higher proficiency is generally reported to trigger larger P600 effects (Alemán Bañón et al., 2018, 2021; Bice & Kroll, 2021; Gabriele et al., 2021; Nichols & Joanisse, 2019; but see Armstrong et al. 2018). Interestingly, Alemán Bañón et al. (2018) compared the impact of two different measures of proficiency, namely d-prime scores derived from a grammaticality judgment task performed during EEG recording and overall L2 proficiency derived from standardized grammar tests. Whereas task-related proficiency correlated with P600 amplitudes in all conditions, overall proficiency scores did not.

Few ERP studies have investigated immersion duration effects, and just one reported a significant effect on the amplitude of late components (Alemán Bañón et al., 2021). In line with Caffarra et al. (2015), other studies that tested immersion (Table 9.1A) showed early negativities (either LAN or N400, but see Meykadeh, Golfam, Nasrabadi et al. 2021), but only with intermediate or long immersion duration.

Summary of ERP Findings

The ERP studies presented here show that the emergence of early negativities mirroring automatic (native-like) processing is not solely driven by L2 morphosyntactic knowledge/proficiency. LAN effects have been reported in two studies testing determiner-noun violations (Caffarra et al., 2017; Nichols & Joanisse, 2019). However, many studies have failed to find LAN effects not only in L2 but also in native speakers, demonstrating that such findings cannot be related to a low level of morphological knowledge. N400 effects were found to mirror intermediate stages of L2 knowledge only in some studies (Díaz et al., 2016; Martinez de la Hidalga et al., 2021), whereas in other studies N400 effects (followed by P600s) mirrored native-like processing (Zawiszewski & Laka, 2020; Bice & Kroll, 2021). The only ERP component that was reliably affected by proficiency was the P600, in line with Caffarra et al.'s finding. However, the P600 amplitude was also reduced by L1-L2 dissimilarities, later AoA, and shorter immersion duration. In other words, evidence coming from recent ERP research shows that additional (grammar- and speaker-related) factors should be taken into account when predicting the time course of L2 morphological processing.

Table 9.1
Experimental studies investigating morphosyntactic violations

Table 1A

Study	L1	L2	Feature	Constituents	L1-L2	AOA	PRF	IMM	N400	LAN	P600
Meulman et al. (2015)	Polish/Russian	German	Tense/Finiteness Gender	VP Det-N	S D	L L	H H	L L	NA NA	NA NA	X X (AOA)
Díaz et al. (2016)	Spanish	Basque	Case Number Number	NP Obj-V Subj-V	D D S	E L E L E L	H L H L H L	L L L L L L	X (delayed) X (delayed) X NA NA	 NA NA	 X (marginal) X (early) X
Alemán Bañón et al. (2017)	English	Spanish	Number Gender	NP-Adj NP-Adj	D D	L L	H H	S S			X (larger) X (smaller)
Caffarra et al. (2017)	Basque	Spanish	Gender	Det-N	D	E	H	L		X	X
Alemán Bañón et al. (2018)	English	Spanish	Number Gender	NP-Adj NP-Adj	D D	L L	L H L H	S S S S			X X X
Armstrong et al. (2018)	Chinese	English	Number	Subj-V	D	L	L	I			X
Nichols &	English	French	Gender	Det-N	D	E	L	I/L		X (AOA)	X* (AOA, PRF)

Joanisse (2019)											
Zawiszewski & Laka (2020)	Spanish Basque	Basque Spanish	Case - ergative Case - dative Case - allative Case - accusative Case - dative Case - allative	NP NP NP NP PP PP	D S S D S S	E E E E E E	H H H H H H	L L L L L L	X X X X X		X* X X* X* X*
Alemán Bañón et al. (2021)	English	Spanish	Person - 1st Person - 3rd	Subj-V Subj-V	S S	L L	H H	S S			X (PRF) X (IMM)
Bice and Kroll (2021)	Spanish	English	Number	Subj-V	S	E	H	L	X	NA	X (PRF)
Cheng et al. (2021)	Chinese	English	Number	Subj-V	D	L	L	S			X*
Gabriele et al. (2021)	English	Spanish	Number Number Gender	Subj-V NP-Adj NP-Adj	S D D	L L L	L L L	NA NA NA			X (PRF) X (PRF) (PRF)
Liang et al (2021)	English/Dutch/Italian/Polish/Swedish	Chinese	Aspect	VP	D	L	H	S	*		
Martínez de la Hidalga	Spanish	Basque	Number Person Number	Subj(erg)-V Subj(erg)-	D D S	E E E	H H H	L L L	X* X* *		X* (smaller) X* (smaller) X (larger)

et al. (2021)			Person	V Subj(abs)-V Subj(abs)-V	S	E	H	L	*		X (larger)
Meykadeh et al. (2021)	Turkish	Farsi	Number	Subj-V	S	E	H	L			X
Morgan-Short et al. (2022)	English	Spanish	Number	Subj-V	S	L	L	NA			X

Table 9.1B

Study	**L1**	**L2**	**Feature**	**Constituents**	**L1-L2**	**AOA**	**PRF**	**IMM**	**Main findings**
Wartenburger et al. (2003)	Italian	German	Person/Number/Case	Subject-verb	S	E/L	H/L	L/I/S	L1-L2 overlap in left IFG at early AoA. Increased IFG activation in the late-AoA group.
Sakai et al. 2004	Japanese	English	Tense	Single word (verb)	D	L (During experiment training)	L	NA	L1-L2 overlap in left IFG
Tatsuno and Sakai (2005)	Japanese	English	Tense	Single word (verb)	D	L (During experiment trainin	L/H (two groups)	NA	Less left IFG activation corresponding to higher proficiency

						g)			
Hernandez et al. (2007)	Spanish	English	Gender	Single word (noun)	D	E/L	H	NA	Greater activation for L2 late learners.
Lehtonen et al. 2009	Finnish/Swedish	Finnish/ Swedish	Inflected vs. non-inflected nouns	Single word (noun)	D	E	H	NA	Greater left IFG activation for Finnish vs. Swedish inflected words
Pliatsikas et al. (2014)	Greek	English	Tense	Single word (verb)	S	L	H	I	Overlapping activation patterns for natives and non-natives. L2 immersion modulates activation difference between regular and irregular in left IFG. L2 proficiency modulates activation difference between regular and irregular in left caudate modulated.
Yan et al. (2016)	Chinese	English	Tense	Single word (verb)	D	L	H	NA	Increased activation in left IFG, anterior/posterior STG, MTG, IPL, and BG for regular compared to irregular tense.
Meykhadeh et al. (2021)	Turkish	Persian	Person, Number	Subject-verb	S	L	H	I	L1-L2 overlap L1: Left pars opercularis more sensitive to ungrammatical (relative to grammatical conditions). L2: Greater activation in left STG for ungrammatical compared to grammatical conditions.

Note. We report the speakers' ***L1***, ***L2***, morphosyntactic ***Feature*** tested, ***Constituents*** involved. ***L1–L2*** (S: similar; D: different): "similar" when the feature at issue was present in both languages and the violation involved the same constituents in both languages, "different" in all the other cases. ***AOA*** (E: early; L: late): "early" for a mean AoA value below 10 years; "late" for a mean AoA above 10. ***PRF*** (L: low; H: high) was "low" for mean proficiency values below 75%; "high" for mean values above 75%; ***IMM*** (S: short; I: intermediate; L: long) was "short" for mean length of residence in the L2-speaking country less than 2 years, "intermediate" for mean values between 2 and 5 years, "long" for mean values above 5 years. Table 9.1A summarizes the ERP literature. The grey boxes identify the factors that were formally analyzed, either in traditional group-analyses or in correlation/regression analyses in relation with ERP effect amplitudes (in this last case, we report their effect in parentheses). In the ***N400/LAN/P600*** columns X stands for the presence of an ERP effect (violation – control condition). The asterisk (*) stands for smaller amplitude compared to native speakers. Table 9.1B summarizes the fMRI literature. Legend: IFG: Inferior Frontal Gyrus; STG: Superior Temporal Gyrus; IPL: Inferior Parietal Lobule; BG: Basal Ganglia; NA= not available.

Functional Magnetic Resonance Imaging (fMRI)

The slow temporal resolution that characterizes fMRI makes it unsuitable for capturing the time course of neurocognitive processes, but its exquisite spatial resolution can give invaluable insights into the brain areas that are actively involved during a linguistic task (for more on this method, see Kousaie & Klein, this volume). fMRI is therefore an extraordinary resource to assess the extent of overlap or segregation in the cortical representations of L1 and L2 and modulation of brain activation patterns by experience- and grammar-related factors. Yet, fMRI investigations on L2 morphological processing are still scant, and the evidence for the effect of grammar- and speaker-related variables appears to be quite fragmented. Moreover, unlike ERPs, there is no meta-analysis or review of fMRI studies specifically on L2 morphological processing to date. Therefore, the review below is based on the available fMRI literature that could be identified at the time of writing this chapter.

fMRI studies investigating L2 morphological processing have mostly examined English regular and irregular tense inflection at the single-word level. Few studies have investigated the processing of morphosyntactic relations in sentences (e.g., subject-verb agreement, see Table 9.1B for an overview). Overall, the available evidence points to substantial neuroanatomical overlap between L1 and L2 morphological systems. Across studies (see Table 9.1B and references therein), consistent activation patterns have been identified both cortically, especially in left frontal regions, and subcortically, in the left caudate nucleus, the basal ganglia, and the cerebellum.

Research on native and non-native processing offers two different functional interpretations of the involvement of the left inferior frontal gyrus (IFG) during morphological processing. Some proposals emphasize the domain-specific nature of the morphosyntactic computations supported by this region (e.g., Friederici, 2017), especially with regard to the pars opercularis. In contrast, other accounts associate this region with domain-general cognitive control mechanisms (e.g., Bornkessel-Schlesewsky & Schlesewsky, 2013) that support linguistic processing, in light of the white-matter tracts that connect this area with subcortical regions such as the caudate nuclei. Interestingly, studies with bilingual speakers have functionally associated these subcortical regions with the monitoring and control functions that are triggered when the linguistic system is required to switch between two languages (Branzi et al., 2021; Crinion et al. 2006; Lehtonen et al., 2005; see Abutalebi, 2008 for a review).

Grammar- and speaker-related variables can influence the amount of language control necessary to monitor L1 interference, and thus the degree of automaticity with which L2 processing mechanisms are performed (see Abutalebi, 2008; Polczynska & Bookheimer, 2021; Roncaglia-Denissen & Kotz, 2016 for reviews). Neurophysiologically, such factors can modulate the degree of efficiency of a given area in supporting a specific cognitive function. In fact, the neuronal organization of a brain region could be optimized for native language processing and its automatized mechanisms, but not for the L2 and its more controlled computations (Abulalebi, 2008; Indefrey, 2006). The involvement of larger neuronal populations, and so the emergence of stronger activation patterns, could therefore compensate for the lower neuronal and computational efficiency of the L2. As L2 processing becomes more automatic, the neuronal organization of the involved region(s) could become more efficient, leading to a change in the linkage between performance and strength of activation (Indefrey, 2006), i.e., a decrease in activation.

Grammar-Related Factors

Contrary to electrophysiological studies, inherently linguistic factors such as L1-L2 similarity have received scarce attention in the fMRI literature on morphological processing. Previous reviews have suggested that, across linguistic domains, typologically similar languages are more likely to show a convergent neuroanatomical representation (Polczynska & Bookheimer, 2021; Roncaglia-Denissen & Kotz, 2016). However, the studies reviewed in Table 9.1B suggest that neuroanatomical overlap can also occur across typologically dissimilar languages. Converging patterns of activation in left IFG regions have been found in comparisons between languages that differ in their degree of morphological richness (e.g., agglutinating Finnish vs. fusional Swedish morphology in simultaneous bilingual speakers, Lehtonen et al. 2005), or in the way a morphological feature is expressed on a verb (e.g., tense in English L2 vs. Japanese and Chinese as L1, Sakai et al. 2004; Tatsuno & Sakai, 2005; Yan et al. 2016). These results are similar to contrasts between languages that share morphosyntactic features (tense in Greek and English, Pliatsikas et al. 2014; person/number in German and Italian, as in Wartenburger et al. 2003, and in Persian and Turkish, Meykadeh, Golfam, Batouli, & Sommer, 2021).

To complicate matters further, in both morphologically similar and dissimilar L1-L2 pairs, the neural overlap can be accompanied by either quantitative or qualitative differences. For example, Lehtonen et al. (2009) showed that the processing of the complex agglutinative morphology of Finnish yielded stronger activation of the left IFG compared to the simpler fusional morphology of Swedish. Meykadeh et al. (2021) tested Turkish and Persian, which similarly encode person and number agreement on the verb (and showed that within their common left fronto-temporal network, the left IFG was more engaged by grammatical sentences in the L1 (Turkish), whereas the left posterior temporal gyrus was more sensitive to ungrammaticality in the L2 (Persian).

Part of the difficulty in identifying the contribution of cross-linguistic similarity to the neural representation of L2 morphology is likely to be methodological in nature. Although L1-L2 similarity is usually acknowledged in the rationale of the functional neuroimaging studies we reviewed, it is neither entered in the experimental design so as to test the effect of shared vs. non-shared morphological features, nor is a precise definition of cross-linguistic (dis-)similarity provided, contrary to the ERP studies previously described. It is therefore difficult to disentangle the effect of L1-L2 similarity from that elicited by speaker-related variables. For example, Wartenburger et al. (2003) reported overlapping patterns of activation between Italian L1 and German L2 (both languages similarly mark number and gender information in determiners, nouns, adjectives, and verbs), but only at high levels of proficiency and early AoA (i.e., when more automatic and efficient processing is expected). With a later AoA and lower proficiency, quantitative differences between L1 and L2 emerged. Similarly, the partial L2 specialization in left temporal areas reported by Meykadeh et al. (2021) could be modulated by the different AoA of Persian and the different immersion that characterized the languages (naturalistic for L1 and a mixture of naturalistic and formal for L2). These factors could affect the efficiency and native-likeness of the response, even at very high levels of L2 proficiency. In this respect, fMRI findings align with ERP evidence on the interaction between L1-L2 similarity and speaker-related factors.

Speaker-Related Factors

Clearer but not fully consistent scenarios emerge for the role of proficiency and AoA. A negative correlation is usually identified between proficiency and neural activation: As proficiency progresses towards a native-like level, L2 activation in a given area decreases (Tatsuno & Sakai, 2005) and becomes indistinguishable from the L1. Pliatsikas et al. (2014) reported a positive correlation between the size of the regularity effect (regular > irregular forms) in the left caudate nucleus and the L2 proficiency of a group of late Greek-English bilinguals. As English proficiency increased, so did the efficiency with which English morphologically complex words were processed, such that left-caudate activation became statistically indistinguishable from that of native speakers.

When proficiency is kept constant across groups, AoA has been found to influence morphological processing in the L2 and lead to quantitative modulations in activation patterns, as evidenced by the greater left IFG involvement associated with categorizing gender-irregular nouns for late learners compared to native speakers of Spanish (Hernandez et al., 2007). Likewise, highly proficient Italian-German speakers who had acquired their L2 late (> 6 years) showed stronger left IFG activation for the L2 compared to the L1 in response to morphosyntactic violations (Wartenburger et al., 2003). In both studies, following Indefrey (2006), the stronger involvement of left IFG in the L2 could be due to this region's lower efficiency in processing a later-learned language. However, in contrast to these studies, Pliatsikas et al. (2014) observed no quantitative differences between native speakers and late-learners of English in the patterns of activation elicited by regular and irregular past-tense processing in a lexical decision task. This suggests that efficient, native-like neuronal organization can be achieved even when the L2 is acquired late.

Task-related differences may explain the seemingly inconsistent conclusions reached by the three studies. Compared to lexical decision tasks (as in Pliatsikas et al., 2014), gender categorization or grammaticality judgments (as in Hernandez et al., 2007, and Wartenburger et al., 2003, respectively) involve additional rule-based mechanisms aimed at verifying inflectional consistency across lexical items (e.g., noun-verb, determiner-noun). Such mechanisms are activated even when not explicitly required, as in gender-decision tasks (see Cubelli et al., 2005). Several single-word production studies have shown that patterns of cortical activations during lexical access are modulated by the speakers' L2 proficiency (low > high proficiency), but not by AoA, which appears to have a more sizeable impact on rule-based morphosyntactic processing (Abutalebi, 2008; Indefrey, 2006; Wartenburger et al. 2003). Thus, the distinct effects of AoA across the three studies could be due to the different sensitivity that behavioral tasks have to this speaker-related factor.

To our knowledge, no hemodynamic study has so far systematically tested whether L2 immersion duration has any effect on the neuroanatomical correlates of L2 morphological processing. Of the eight functional neuroimaging studies included in this review, only three report their participants to have been naturalistically immersed in the L2 environment, ranging from short to long periods (Meykhadeh, Golfam, Nasrabadi et al. 2021; Pliatsikas et al. 2014; Wartenburger et al. 2003). Both Pliatsikas et al. (2014) and Wartenburger et al. (2003) found L1-L2 overlap with increasing immersion, thus suggesting that naturalistic exposure can guide the L2 towards reaching a native-like neural representation. This is in line with ERP studies showing that learning in immersion-like contexts leads to electrophysiological signatures more fully typical of native speakers (Morgan-Short et al., 2012). However, more research is necessary to determine whether immersion duration is a strong and independent predictor of the cortical representation of L2 morphology (for the effect of immersion on volumetric brain changes, see Korenar & Pliatsikas, this volume).

Summary of fMRI Findings

The findings reviewed above suggest that L1-L2 similarity alone is not a robust and independent predictor of the neural representation of L2 morphology. However, research that systematically manipulates this factor or uses techniques with the finest spatial resolution, such as invasive brain stimulation in neurosurgical studies, would confirm this conclusion. Speaker-related factors have the most tangible effects on the neural representation of L2 morphology. However, as will be discussed below, when examining the role of such variables and their predictive power, it is important to consider the degree of collinearity that exists between AoA, proficiency, and immersion duration (i.e., early exposure to the L2 is usually associated with naturalistic immersion, thus higher proficiency).

Current Trends and Future Directions

Native-likeness refers to the ability of speakers to process stimuli in an L2 (almost) as efficiently and automatically as in their native language. The degree of overlap between L1 and L2 electrophysiological and neuroanatomical correlates is taken to be a marker of the level of native-likeness achieved by a group of speakers. The greater their similarity, the more native-like, and so the more efficient and automatic, L2 processing is assumed to be. Our review shows that quantitative and qualitative modulations relative to native patterns of reference can depend on grammar- and speaker-related factors.

Inherent to the definition of native-likeness provided above is a controversial assumption that characterizes the profile of native speakers, namely their homogeneity in terms of processing routines, as well as the homogeneity of the electrophysiological and hemodynamic responses to stimuli in their native language. A legitimate question is whether it makes sense to consider native speakers as a homogeneous group, given the increasing bi/multilingual status and globalization of the world's population. Many studies have suggested reconsidering the "gold standard" for nativelikeness in ERPs and investigating L1 and L2 processing along a continuum (e.g., Tanner et al. 2013, 2014; see also Freunberger et al. 2022). Future challenges in the field could therefore be to identify the variables that can account for inter-individual variability both in native and non-native processing, as well as the appropriate methodology to investigate and account for such variability (see for example, Fromont, and Luque & Covey, this volume).

Factors Affecting Morphological Processing

Our review suggests that to date, none of the different grammar- and speaker-related factors considered here are independent predictors of L2 native-likeness. This is partly due to differences in the depth with which the different techniques have been used to examine the effects of specific predictors, as in the case of L1-L2 similarity and proficiency, as well as the number of studies adopting these different methodologies to investigate L2 morphosyntactic processing.

ERP research has proceeded as far as to investigate (dis-)similarities in single features and the position in which they are expressed within morphosyntactic relations across languages. In contrast, fMRI studies have predominantly focused on the regular vs. irregular past tense opposition and how it is handled across broadly defined typologically similar or dissimilar languages. Future hemodynamic studies should therefore go beyond single-word processing and assess L1-L2 (dis-)similarities at the sentence level. In this respect, a fruitful testing ground is the contrast between morphological features and their presence/absence in L1 and L2 languages, thus extending and complementing existing single-word (e.g., Hernandez et al. 2007) and sentence-level L1 studies (Carreiras et al., 2015; Mancini et al., 2017; Quiñones et al., 2014, 2018).

Like L1-L2 similarity, proficiency encompasses distinct components - such as global and task-related proficiency – that can differentially affect the response of interest. Empirical evidence concerning the impact that distinct proficiency assessments have on morphological processing comes from ERP research, while to the best of our knowledge, fMRI studies have not addressed this issue. Task-related proficiency reflects a specific and less naturalistic measure of proficiency, which, unlike global proficiency, cannot provide a complete measure of the real linguistic abilities of L2 speakers in everyday life. Consequently, the role that this type of proficiency has in the modulation of late ERP components should be interpreted with more caution. One possibility, albeit more radical, would be to abandon the general concept of proficiency and rely on more specific indices of L2 experience such as the type and amount of L2 exposure and immersion (e.g., Ullman, 2014) and/or the frequency of L2 use (e.g., Martinez de la Hidalga et al., 2021; Osterhout et al., 2006).

A Note on Non-Invasive Brain Stimulation

Research on non-invasive brain stimulation (NIBS) investigates the effects that magnetic and electric stimulation, namely TMS (transcranial magnetic stimulation) and tDCS (transcranial direct current stimulation), have on participants' performance (see Pandža, this volume). In language research, participants are generally asked to produce a word/sentence or to perform a metalinguistic task (e.g., grammaticality judgments) while specific brain regions are stimulated. The stimulation can either have disruptive effects, mirrored by longer reaction times and/or lower task accuracy, or it can positively enhance the participants' performance, leading to shorter reaction times and/or higher accuracy.

NIBS research on L2 acquisition is still in its early stages (see Pandža, this volume). For instance, studies of picture naming (Tussis et al., 2017) and language switching (Holtzheimer et al., 2005) have been reported. Although these studies did not manipulate morphology or morphosyntax specifically, their results suggest that research on L2 processing could benefit from non-invasive brain stimulation techniques.

Available NIBS evidence on native language processing with healthy and brain-damaged speakers points to a causal role of the left IFG in morphosyntactic processing (for a review see Maran et al., 2022) and of the temporal lobe in the retrieval of irregular past tense verbs in English (Holland & Lambon-Ralph, 2010). These findings lend support to the correlational evidence provided by the hemodynamic studies discussed above, suggesting that NIBS could provide useful insights into the neural representation of the L1 and L2.

Final Remarks

In the introduction to this chapter, we highlighted theoretical, historical, and methodological issues behind the lack of a comprehensive neurolinguistic account of L2 morphological processing. Our review of recent ERP, fMRI, and NIBS literature shows that while historical limitations have been overcome, there are still some methodological aspects that should be considered in future research. A case in point is represented by the use of rigid categories to assess the effects of experience-related variables (i.e., division into distinct low- and high- proficiency groups). L2 data are subject to a high degree of variability, as it is notoriously difficult to find bilingual speakers with homogeneous linguistic profiles, and this variability is not accounted for in the statistical analyses. New methodological approaches are thus needed (see Fromont, this volume).

Finally, ERP studies have provided a fine-grained picture of the temporal dynamics related to the processing of different morphosyntactic features and relations, while a more fragmented scenario emerges from fMRI and NIBS. Brain areas and networks involved during L2 morphological processing have been identified but, to date, it is still hard to define whether these networks change as a function of different morphosyntactic features/relations.

Further Readings

This article attempts to provide a set of global principles that determine the neuroanatomical overlap of languages in the brain.

> Połczyńska, M.M., & Bookheimer, S.Y. (2021). General principles governing the amount of neuroanatomical overlap between languages in bilinguals. *Neuroscience & Biobehavioral Reviews*, *130*, 1-14. https://doi.org/10.1016/j.neubiorev.2021.08.005

This article discusses issues related to a rigid concept of native-likeness in ERP research.

> Freunberger, D., Bylund, E., & Abrahamsson, N. (2022). Is it time to reconsider the ‘gold standard’ for nativelikeness in ERP studies on grammatical processing in a second language? A critical assessment based on qualitative individual differences. *Applied Linguistics*, *43*(3), 433-452. https://doi.org/10.1093/applin/amab058

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