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Electrophysiological Approaches to Understanding Second Language Acquisition: A Field Reaching its Potential

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The present article provides a review of results from electrophysiological studies of the neurocognition of second language. After a brief introduction to event-related potentials (ERPs), the article explores four sets of findings from recent second language (L2) ERP research. First, longitudinal L2 ERP research has demonstrated that L2 neurocognitive processing changes qualitatively with time. Second, research has shown that L2 learners can evidence nativelike ERP effects for L2 grammatical features that are present in their first language (L1) as well as for features that are unique to their L2 but may have more difficulty processing features that are present in their L1 but that are instantiated differently in their L2. Third, emerging research has revealed that individual differences in ERPs can be accounted for by linguistic and nonlinguistic factors. Finally, recent empirical studies have shown that explicit and implicit training contexts can lead to nativelike ERP effects at high levels of proficiency, but that implicit contexts may lead to the development of a fuller nativelike processing signature, at least for syntactic processing. With continued interdisciplinary approaches and sophisticated research designs, L2 ERP research is only beginning to reach its potential and promises to uniquely inform central questions of second language acquisition.

As the field of second language (L2) acquisition matures, there is growing interest in research that can provide fine-grained information about how different aspects of L2 are processed and what factors are involved in the development that leads to such processing. One methodological approach that has great potential to inform these central questions of L2 acquisition is electrophysiology, which is a technique for recording electrical voltage potentials produced by cellular activity, including activity in neurons. Recorded voltage potentials can be analyzed in relation to cognitive events, such as processing particular aspects of language, and can yield interpretable patterns of data called event-related potentials (ERPs). ERPs provide information about neurocognitive processing that is multidimensional and fine-grained in regard to the timing and nature of processing, and thus can provide a unique and complementary set of data

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related to L2 acquisition and processing. Indeed, the body of L2 research utilizing electrophysiology has paralleled the expanding body of first language (L1) ERP research that examines phonological, lexical/semantic, morphosyntactic, and syntactic processing, among other aspects of language (for reviews of L1 research, see Kaan, 2007; Kutas & Federmeier, 2011; Steinhauer & Connolly, 2008; Swaab, Ledoux, Camblin, & Boudewyn, 2012; for previous reviews of L2 research, see Moreno, Rodríguez-Fornells, & Laine, 2008; Mueller, 2005; Steinhauer, White, & Drury, 2009; van Hell & Tokowicz, 2010). Particularly striking is the increasing body of ERP research on the neurocognition of L2 (morpho)syntax, including 21 peer-reviewed articles that have been published in the 5 years between 2008 and 2013.[1] The present article provides a review of this body of research. First, the article briefly introduces ERPs along with their advantages and disadvantages and then presents a general overview of some of the primary ERP effects found in L1 processing that can serve as a basis for interpreting L2 ERP research. Next, the article touches upon the central findings from earlier L2 ERP research that motivated the trends of more recent L2 ERP research. Finally, a review of the ERP research related to the neurocognition of L2 (morpho)syntax published between the years 2008 and 2013 is discussed more thoroughly in regard to (a) the development of L2 neurocognitive processing over time (i.e., with increasing proficiency and exposure), (b) how L1-L2 similarity affects L2 neurocognitive processing, (c) individual differences in L2 neurocognitive processing, and (d) how different types of contexts or training conditions may affect L2 neurocognitive processing.

EVENT-RELATED POTENTIALS AND L1 NEUROCOGNITIVE PROCESSING

ERPs originate from scalp-based recordings of electrical voltage potentials that are produced by neuronal activity as people process information (e.g., auditorily presented sentences). The recorded signal, called the electroencephalogram, is segmented into epochs of signal that are time-locked to the presentation of stimuli representing a particular cognitive event, for example, a part of a sentence that elicits (morpho)syntactic processing. Several instances of these epochs (generally 20–40) are then averaged together, such that the part of the signal that is common to the particular type of stimuli is maintained whereas noise that is not related to the stimuli is attenuated. The resulting averaged waveform is called the ERP, which represents the processing related to the event of interest and which can be characterized by its temporal information, amplitude, polarity, and distribution over the scalp. (Note, however, that ERPs do not provide information about the location of the neural generators of the observed signal.) Given the richness of this information, ERPs provide a powerful way to measure cognitive processing in real time (for comprehensive introductions to ERPs, see Handy, 2005; Luck, 2005, 2012).

Several researchers, however, have pointed out that both the advantages as well as the disadvantages need to be considered when engaging in and interpreting ERP research (e.g., Luck, 2005; Morgan-Short & Tanner, 2014). In regard to their advantages, ERPs can be highly informative because they

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provide researchers with data that is multidimensional (e.g., data about temporality, amplitude, polarity, and scalpal distribution). They are also very sensitive, especially in regard to the timing of processing as compared to other neuroimaging methods (e.g., functional magnetic resonance imaging). A further important advantage is that they can be observed without any secondary task to which a participant has to respond, although in L2 research, ERPs are typically recorded as participants engage in a linguistic task. There are disadvantages that must be considered as well: ERPs are expensive to acquire, particularly in regard to the initial purchase of equipment. They require the presentation of lots of stimuli in order to have enough power to obtain an averaged signal. They are also time-consuming to collect and to analyze. However, when the advantages outweigh the disadvantages in regard to a particular research question, ERPs can provide a unique set of data that can greatly increase our understanding of cognition, including our understanding about how languages are processed.

In studies of linguistic processing, ERP researchers have employed a variety of experimental paradigms (e.g., priming, lexical decision, semantic categorization, and sentence processing violation paradigms; for an overview of various experimental paradigms used in language-related ERP research, see Morgan-Short & Tanner, 2014). Perhaps the most commonly used paradigm for both L1 and L2 (morpho)syntactic processing within sentential contexts is the violation paradigm, which examines how certain types of violations of linguistic structures affect the ERP waveform as compared to nonviolated linguistic structures. For example, one might examine the ERP effect to the subject-verb agreement violation evident in the word *hopes* in the sentence "The elected officials hopes to succeed" as compared to *hope* in the same sentence (Osterhout & Mobley, 1995, p. 742). For this and other (morpho)syntactic violations, the most common ERP effect in native-speakers is an increased posterior positivity in the waveform that starts around 600 ms for the violation word as compared to its correct counterpart (e.g., Osterhout & Mobley, 1995). This ERP effect, typically called a P600, with P indicating that it is a positive effect and 600 indicating the point in time (ms) when the effect is often observed, is also elicited by nonviolation stimuli such as garden path and syntactically complex sentences (for further discussion regarding the elicitation of the P600, see Morgan-Short, Faretta-Stutenberg, & Bartlett-Hsu, in press; Swaab et al., 2012).

Morphosyntactic violations, (e.g., "officials hopes") can also yield an increased negativity in the ERP waveform for violation stimuli as compared to the waveform for correct stimuli around 300–500 ms across more anterior electrodes (e.g., Osterhout & Mobley, 1995). This effect has been called a AN (for anterior negativity) when its scalpal distribution is bilateral, and a LAN (for left anterior negativity) when it is maximal over the left hemisphere.[2] Note that this modulation of the ERP waveform is not elicited by (morpho)syntactic violations as consistently at the P600 effect (e.g., Allen, Badecker, & Osterhout, 2003; for further discussion regarding the elicitation of the LAN, see Morgan-Short et al., in press; Tanner, 2014; Tanner & van Hell, 2014),

A third effect that is reliably elicited in native-speakers, but not to (morpho)syntactic violations, is a negativity that occurs over the posterior scalp region around 300–500 ms after the presentation of a lexical-semantic violation,

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for example, *socks*, in the sentence "He spread the warm bread with socks" as compared to a correct word, for example, *butter*, in the same sentence (Kutas & Hillyard, 1980, p. 203). This effect, called a N400 (N for negativity and 400 for the typical time at which the effect peaks) is also elicited by other manipulations of lexical and semantic information, such as word frequency, word position, and contextual integration (for further discussion regarding the elicitation of the LAN, see Kutas & Federmeier, 2011; Morgan-Short et al., in press).

Although there are significant debates in the L1 ERP literature regarding the precise conditions that elicit these effects and the interpretation of their functional significance (e.g., Bornkessel & Schlesewsky, 2008; Kutas & Federmeier, 2011; Kuperberg, 2007; Tanner & van Hell, 2014), these effects serve as a useful basis for exploring the neurocognition of L2 processing.

L2 NEUROCOGNITIVE PROCESSING

Growing interest in the neurocognition of L2 is reflected not only in the increasing number of L2 ERP studies that have emerged since the seminal Ardal, Donald, Meuter, Muldrew, and Luce (1990) and Weber-Fox and Neville (1996) studies, but also in the number of past reviews of such research that have highlighted important patterns of findings in the research. First, L2 (morpho)syntactic processing often differs from that of L1. Indeed, Steinhauer et al. (2009) point out that several early L2 ERP studies (e.g., Hahne & Friederici, 2001; Weber-Fox & Neville, 1996) suggested that there were fundamental differences in the neurocognitive processes underlying L2 syntax as compared to L1. Second, several reviews of L2 ERP research (Kotz, 2009; Mueller, 2005; van Hell & Tokowicz, 2010) have discussed how L1-L2 similarity affect processing and point to evidence that nativelike ERP responses can be found for grammatical features that are present and similar in L1 and L2 or unique to L2, but they are less likely to be found for grammatical features that are dissimilar (e.g., Sabourin & Stowe, 2008; Tokowicz & MacWhinney, 2005). Third, all reviews of L2 ERP research have concluded that L2 proficiency affects whether nativelike processing can be evidenced in L2 learners. Based on their review of the literature, Steinhauer et al. (2009) proposed a developmental progression of ERP responses to L2 (morpho)syntactic processing based on proficiency, with no ERP effects or N400s found at novice and very low proficiency levels (e.g., Friederici, Steinhauer, & Pfeifer, 2002; Osterhout, McLaughlin, Pitkänen, Frenck-Mestre, & Molinaro, 2006), P600s found at low to intermediate levels of proficiency (e.g., Osterhout et al., 2006), and ANs and P600s found at the highest levels of proficiency (e.g., Friederici et al., 2002). This review pointed out a need for longitudinal research that could better show whether this progression could be evidenced within learners. In addition to arriving at conclusions related to whether L2 neurocognitive processing resembles that of L1 and how this may be affected by L1-L2 similarity and L2 proficiency, reviews of previous research laid out questions that undoubtedly laid the groundwork for more recent empirical studies of L2 ERP research: Recent research has further explored the development of ERP responses longitudinally and has delved into the complexity of how L1-L2 similarly affects processing. It

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has also heeded calls to consider individual differences (Osterhout et al., 2006) and potential effects of the context of learning (Steinhauer et al., 2009). Here we review the results from recent L2 ERP studies (peer-reviewed articles published between 2008 and 2013) that further explore these issues.

ISSUES IN L2 NEUROCOGNITIVE PROCESSING

One of the central questions still being addressed in L2 ERP research is whether second language learners can show neurocognitive processing signatures that are similar to those of native speakers. However, even with additional research on this issue, the question remains open as conflicting results have continued to emerge. Guo, Guo, Yan, Jiang, and Peng (2009) examined processing of English verb subcategorization violations in a group of native speakers of Chinese who began to learn L2 English around the age of 11.2 years, who had never lived in an English-speaking environment, and who rated themselves fairly high on a scale of English proficiency. Results showed that violations yielded a P600 response in native English speakers but a N400 response in L2 learners, which led the researchers to conclude that the L2 learners relied on shallower, semantic processing as compared to syntactic processing evidenced in native speakers. Pakulak and Neville (2011) also found processing differences between L1 and L2 for native speakers of German learning L2 English who had an average age of acquisition of 11.05 years, who lived in an English-speaking environment, and who were matched in proficiency to native English speakers on a standard speaking and grammar test. English phrase structure violations yielded an extended AN and a P600 in native speakers but only a P600 in the L2 group. Because proficiency was matched between the groups, the researchers concluded that the neural organization of syntactic processing is sensitive to age of acquisition effects and that more automatic processes, as reflected by the AN, are particularly susceptible to age of acquisition effects.

These sets of findings contrast with those of Bowden, Steinhauer, Sanz, and Ullman (2013) who examined syntactic processing in two groups of English native-speakers who were studying L2 Spanish at the university level. One group of Spanish L2 learners began to acquire Spanish at an average age of 14.1 years, had completed an average of 2.0 semesters of university-level Spanish classes, had never lived in a Spanish-speaking environment, and were classified at a low-intermediate level of proficiency based on a standard speaking test. The second group of Spanish L2 learners began to acquire Spanish at an average age of 12.4 years, had completed an average of 6.9 semesters of university-level Spanish classes, had lived in a Spanish-speaking environment for at least one semester, and were classified at an advanced level of proficiency based on a standard speaking test. In regard to processing Spanish phrase structure violations, native Spanish speakers evidenced a LAN, a P600, and a late AN. The low-intermediate proficiency L2 speakers did not evidence any significant ERP effect. However, the advanced proficiency L2 group evidenced statistically equivalent LAN and P600 effects as compared to native speakers, suggesting that L2 speakers can rely on processing mechanisms that are indistinguishable

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from native speakers. In all, the results of this study suggest that proficiency and experience may affect L2 processing to a greater extent than age of acquisition.

These conflicting results, taken together with similarly conflicting results from previous research (see preceding), can only lead us to conclude that a host of factors may be at play in regard to whether L2 learners are able to rely on similar neurocognitive processes as native speakers for (morpho)syntactic processing. Indeed, this is the direction that L2 ERP research has taken in the past 5 years, with researchers examining issues such as the development of L2 neurocognitive processing over time, how linguistic similarity may impact L2 processing, whether individual differences in linguistic, cognitive, and experiential domains may affect processing, and whether the type of context under which an L2 is learned may affect processing. Each of these issues is considered in turn.

Development over Time of L2 Neurocognitive Processing

Many of the conflicting results of previous L2 ERP research are likely due to the cross-sectional nature of the work, and one of the improvements in the field over the last five years is the implementation of longitudinal research designs that allow researchers to better understand the development of L2 neurocognitive processing while controlling factors that cannot be controlled well with cross-sectional designs. One of the primary differences among L2 ERP studies is the proficiency of L2 learners, which is often only self-reported and, if measured objectively, is generally measured with different instruments across studies. Research has shown that groups of learners at different levels of proficiency have evidenced different ERP signatures to the same stimuli (e.g., Bowden et al., 2013; Hahne, 2001; Hahne & Friederici, 2001), which led to the proposal that ERP effects change qualitatively over time as proficiency and experience increase (Steinhauer et al., 2009). Longitudinal research studies are essential for testing this prediction. Fortunately a body of longitudinal L2 ERP research, which began with Osterhout et al. (2006) and has become more common over the last five years, has shown that nativelike ERP responses can change qualitatively over time (Davidson & Indefrey, 2009; McLaughlin et al., 2010; Morgan-Short, Finger, Grey, & Ullman, 2012; Morgan-Short, Sanz, Steinhauer, & Ullman, 2010; Morgan-Short, Steinhauer, Sanz, & Ullman, 2012; White, Genesee, & Steinhauer, 2012). Davidson and Indefrey (2009) demonstrated that L1 Dutch–L2 German speakers who had not evidenced any ERP response to German case declension violations (a form unique to their L2) during pretesting, developed a P600 response to the form during training that was also elicited at posttesting. (Note, however, that they did not develop such a P600 to gender agreement violations—a form present in their L1 but with a different structure. See the "L1-L2 Similarity in L2 Neurocognitive Processing" section for further discussion about similar patterns of results.) Similarly, White et al. (2012) provided evidence that native speakers of Korean and Chinese, who did not show any ERP effect to L2 English past-tense violations at the beginning of a 9-week intensive English course, developed a P600 to such violations by the end of the course.

Qualitative changes in the ERP signature are not limited to changes from null effects to P600s—other patterns of qualitative change have also been observed.

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McLaughlin et al. (2010) report a series of longitudinal studies that examine the development of neurocognitive processing of different L2 morphosyntactic and morphological structures over the course of the first-year, university-level language classes. In each study, learners evidence a qualitative shift from N400 effects after a few weeks of exposure to P600 effects after an extended amount of exposure, suggesting discrete stages of grammatical processing with increasing exposure and proficiency. A similar pattern of findings was reported in work by Morgan-Short and colleagues (Morgan-Short et al., 2010; Morgan-Short, Finger, et al., 2012; Morgan-Short, Steinhauer, et al., 2012). In this study, a group of learners who were trained on an artificial language demonstrated a N400 response at lower levels of proficiency to both morphosyntactic and syntactic violations. At higher levels of proficiency, these same learners showed a P600 response to morphosyntactic violations and as well as an AN and a P600 response to syntactic violations (see "Effects of Learning Contexts on L2 Neurocognitive Processing" section for more details).

Taken together, the results of longitudinal studies are largely consistent with the pattern of findings from previous cross-sectional L2 ERP research and lend support to the claims made by Steinhauer et al. (2009), which state that for grammatical processing, L2 learners may initially evidence no ERPs or N400s at low levels of proficiency and exposure, P600s at more intermediate stages, and finally ANs and P600s at the highest levels of proficiency and exposure (although the elicitation of ANs may not be expected to be reliable as they are not consistently elicited in L1). Furthermore, this body of longitudinal research has established that this progression is not an artifact of cross-sectional research designs but rather that it manifests itself in individuals as they gain proficiency and experience with their L2. This pattern of findings, however, does not necessarily mean that every learner will experience this shift for every (morpho)syntactic structure. Development may be affected by multiple factors, which are considered in the following section.

L1-L2 Similarity in L2 Neurocognitive Processing

One major area of interest in L2 ERP research has been whether L1-L2 similarity plays a role in the development of nativelike neurocognitive processes. Indeed, more ERP studies have been conducted to examine this issue than any other issue, and evidence is available to be able to arrive at some synthesis of the results for L2 learners at low and intermediate levels of proficiency (Bond, Gabriele, Fiorentino, & Alemán Bañón, 2011; Gabriele, Fiorentino, & Alemán Bañón, 2013; White et al., 2012) as well as for L2 learners at higher levels of proficiency (Foucart & Frenck-Mestre, 2011, 2012; Frenck-Mestre, Foucart, Carrasco, & Herschensohn, 2009; Gabriele et al., 2013; Gillon Dowens, Guo, Guo, Barber, & Carreiras, 2011; Gillon Dowens, Vergara, Barber, & Carreiras, 2010).

In regard to L2 learners at lower levels of proficiency, some studies have found nativelike P600s for linguistic features that are present in the L1 as well as for structures that are unique to the L2 (Bond et al., 2011; White et al., 2012). In White et al. (2012), L1 Korean-L2 English speakers and L1 Chinese-L2 English speakers were presented with sentences with either correct or

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incorrect usages of the English regular past tense. For the L1 Korean speakers, this feature was present in their L1, although it was instantiated in a different form. For the L1 Chinese speakers, this feature was present only in the L2. Neither group evidenced any ERP effect when they were initially tested, but both groups evidenced P600 effects to the stimuli after a 9-week intensive English course that resulted in L2 developmental gains, although the P600 in the L2 Chinese speakers showed a delayed latency. A similar set of findings was found by Bond et al. (2011). In this study, low proficiency L1 English–L2 Spanish speakers, tested in an L1 context, showed P600 effects to agreement structures that were (a) similar to their L1 (i.e., noun-verb number agreement), (b) different from their L1 (i.e., noun-adjective number agreement), and (c) unique to the L2 (i.e., noun-adjective gender agreement), although the P600 to this structure was smaller than that evidenced for noun-adjective number agreement. Gabriele et al. (2013) examined L1 English–L2 Spanish speakers processing L2 number and gender agreement within and across phrases across learners at different proficiency levels. The number feature is present in English, but the gender feature is not. Although the low proficiency L2 speakers did not evidence P600s, which were observed in Spanish native speakers, the L2 learners at intermediate and high proficiency levels did—for both number and gender agreement and both within and across phrases, although the P600 effect was only marginal for gender agreement in intermediate learners. The set of results from these studies are generally consistent with the findings reported in the McLaughlin et al. (2010) study, in which first-year L2 learners evidenced P600 effects for structures that were both present in their L1 and unique to their L2. In all, it appears that at low levels of proficiency, nativelike ERP effects can be found for linguistic structures that are present in learners' L1 or unique to their L2 (Bond et al., 2011). These effects are even more likely to be evidenced when learner proficiency increases (Gabriele et al., 2013; McLaughlin et al., 2010; White et al., 2012). In some cases, nativelike effects can also be found for structures that are different from learners' L1, even at low levels of proficiency (Bond et al., 2011).

Nativelike processing of L2 features has been evidenced more consistently in learners at high levels of proficiency. Gillon Dowens et al. (2010) examined number and gender agreement processing in advanced L1 English-L2 Spanish speakers. Although Spanish instantiates both number and gender features, English instantiates number features only. Thus if L1 similarity plays a role in the development of L2 processing, one might expect qualitatively different patterns of results between number and gender agreement in the L2 speakers. The L2 speakers in this study began to learn Spanish after the age of 20 years, had at least 12 years of immersion experience, reported using their L2 daily, and were tested in an immersion context. The native-Spanish speakers in the study evidenced LANs, P600s, and late ANs to both number and gender agreement between determiner and nouns and between nouns and adjectives. The L2 speakers showed nativelike LAN and P600 effects to both number and gender agreement violations between determiners and nouns as well as an additional late AN for number agreement. Thus they evidenced qualitatively similar effects compared to native speakers regardless of whether the L2 feature was found in their L1. There was, however, a quantitative difference between the size of the P600 effect

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for number and gender agreement, which was larger for number agreement than for gender agreement. Interestingly, the same learners only evidenced a P600, and not a LAN, for number and gender agreement violations between nouns and adjectives. Again the P600 effect was larger in response to number violations as compared to gender violations. In all, the results from this study suggests that L2 learners can evidence nativelike processing, including a LAN effect for a grammatical feature that is not instantiated in their L1, although the elicitation of such an effect may depend on the linguistic structure on which it is expressed, and its magnitude may be affected by L1-L2 similarity.

Gillon Dowens et al. (2011) extended this research with L1 Chinese–L2 Spanish speakers who do not have number or gender features in their native language. Participants in this study had begun to study Spanish after the age of 18 years, were at the end of their third or fourth year of a university degree in Spanish studies, had demonstrated a high level of proficiency on a standard Spanish test, and reported using Spanish daily, but were tested in a L1 context. They were tested with the same materials used in Gillon Dowens et al. (2010). For these learners, neither number nor gender features were available for transfer from their L1, yet the learners evidenced P600 effects for number and gender agreement between determiners and nouns as well as between nouns and adjectives. The learners also evidenced a late AN to both types of number agreement violations and a trend to a late AN to both types of gender agreement violations. Contrary to the L1 English–L2 Spanish learners, the L1 Chinese–L2 Spanish learners did not evidence a LAN effect for any structure, which the authors interpret as evidence that an earlier "less controlled stage of morphosyntactic processing of violations is not available to the Chinese late learners" (Gillon Dowens et al., 2011, p. 1658). However, they also point out that other factors, such as immersion experience and/or proficiency, could account for the difference in the elicitation of the LAN effect across the two studies. In general though, the results from these studies suggest that nativelike P600 effects can be elicited in L2 even for grammatical features that are not present in learners' L1, and that nativelike ANs can be elicited for unique L2 features, although this seems to depend on the typological similarity of the L1 and L2.

Additional fine-grained examination of the role of L1-L2 similarity on L2 neurocognitive processing has been provided through a series of studies conducted by Foucart, Frenck-Mestre, and colleagues (Foucart & Frenck-Mestre, 2011, 2012; Frenck-Mestre et al., 2009). In these studies, gender agreement in L2 French speakers has been examined across speakers from different L1s, for different structures, and for the presence or absence of overt phonological gender realization. In three studies, L2 learners at advanced levels of proficiency in French were tested in a French-speaking environment. In each study, different groups of native speakers of French exhibited P600 effects in response to all gender agreement violations.

Frenck-Mestre et al. (2009) first examined the influence of L1 on L2 processing across different learner groups. L1 English-L2 French learners and L1 German-L2 French learners were tested on gender agreement between plural nouns and postposed adjectives. Gender agreement is a feature that is not present in English. In German, gender agreement is present but does not express itself on

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postposed adjectives that modify plurals nouns. Results from the study showed P600 effects for L1 English speakers but not for L1 German speakers. The study also examined whether overt expression of gender agreement was necessary for L2 learners to be able to process gender in their L2. L1 Spanish–L2 French speakers were exposed to gender agreement between singular nouns and postposed adjectives. Gender agreement is present in Spanish and expresses itself overtly on all singular postposed adjectives. In French, gender agreement expresses itself orthographically but not phonologically on some adjectives (phonologically invariable adjectives) and both orthographically and phonologically on other adjectives (phonologically variable adjectives). L1 Spanish–L2 French speakers demonstrated the same pattern as that of native-speakers of French: P600s were found for both invariable and variable adjectives, although the effects were larger for variable adjectives in both groups. The only difference found between the speaker groups was that the P600 response in the L2 groups was somewhat delayed compared to the native speakers. In all, the results from this study suggest that L2 learners can process features that are unique to their L2 or present in a similar form in their L1, but have more difficulty processing features that are present but expressed in a different form in their L1.

In order to further tease apart how an L2 feature that is present in L1 but expressed differently is processed, Foucart and Frenck-Mestre (2011) continued to examine L2 French gender processing in L1 German speakers for multiple forms: preposed and postposed adjectives and determiners. In this study, the results indicated that the learners could process L2 gender agreement between determiners and nouns, although only a subgroup showed the P600 when the lexical gender of the noun in French did not match the lexical gender in their L1. No evidence was found for a P600 for L2 speakers for noun-adjective gender agreement, even when the surface structure of the noun phrase matched that of their L1 (det-adjective-noun). Note a couple of differences between the determiner-noun and the noun-adjective conditions that might have contributed to the differing results: For the determiner-noun stimuli, all stimuli were singular and participants were asked to consider whether the sentences were semantically acceptable or not. For the noun-adjective conditions, all the stimuli were plural and the participants were asked to judge whether the sentence was correct or not (syntactically and/or semantically). The differing results between the linguistic structures could have also been due to potential proficiency differences for the particular structures. This possibility, however, is difficult to evaluate because the behavioral results are not reported in such a way that it is possible to interpret the results across conditions, although all participant groups seemly came from a similar population (but this was not statistically established). In sum, processing differences were found among the determiner-noun and the noun-adjective conditions, but it is not clear whether these differences were due to the forms themselves or to the task or proficiency differences.

Finally, Foucart and Frenck-Mestre (2012) examined the processing of features unique to a learner's L2. L1 English-L2 French speakers showed a P600, which was more frontally distributed than in native-speakers, for noun-adjective gender agreement when the adjectives followed the nouns, which is the most frequent placement for adjectives in French. The L2 speakers, however, evidenced a

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N400 rather than a P600 for gender agreement on preposed adjectives, which occur less frequently in French. Thus there were processing differences tied to the frequency of the form even though the L2 speakers rejected a similar proportion of violation sentences for the two conditions. For gender agreement on predicative adjectives, native-speakers showed a P600, but L2 speakers did not. The researchers noted, however, that individual differences were apparent with some learners showing a sustained positivity. In a final eye tracking study, the L2 learners showed online sensitivity, which was not distinguishable from L1 speakers, to gender agreement on predicative adjectives, suggesting that L2ers can process grammatical gender over hierarchical distances when they are able to read the stimuli at their own pace.

The results from this body of research reflect a converging but complex picture regarding the influence of L1 features on L2 processing. It appears that L2 learners can evidence nativelike processing of L2 features when they are unique to the L2 (Bond et al., 2011; Foucart & Frenck-Mestre, 2012; Frenck-Mestre et al., 2009; Gillon Dowens et al., 2010; Gillon Dowens et al., 2011; McLaughlin et al., 2010; White et al., 2012), although quantitative differences can be evident between L2 and L1 speakers (Frenck-Mestre et al., 2009) and within learners for features that are either present or absent in L1 (Gillon Dowens et al., 2010). Nativelike processing patterns also appear to be evidenced when the feature is expressed similarly in L1 and L2 (Bond et al., 2011; Foucart & Frenck-Mestre, 2011; Frenck-Mestre et al., 2009; McLaughlin et al., 2010; White et al., 2012). Interestingly, it seems that the most difficulties for processing L2 features come about when the feature is present in the L1 but is expressed according to a different set of rules in the L2 (Foucart & Frenck-Mestre, 2011; Frenck-Mestre et al., 2009). This pattern of findings is also consistent with findings from recent longitudinal work (Davidson & Indefrey, 2009) as well as with findings from earlier L2 ERP research (Sabourin & Haverkort, 2003; Sabourin & Stowe, 2008; Tokowicz & MacWhinney, 2005). In addition to providing converging evidence about the general effects of L1-L2 similarity, this body of recent research had shown that nativelike processing patterns can be evidenced even when the feature is only orthographically (and not phonologically realized; Frenck-Mestre et al., 2009) and when the lexical specification is not shared between the two languages (Foucart & Frenck-Mestre, 2011). An important outstanding issue to be addressed by future research seems to be what specifically interferes with L2 processing when a feature is present in both L1 and L2 but is expressed differently.

Individual Differences in L2 Neurocognitive Processing

Longitudinal L2 ERP research has established that the ERP response elicited by grammatical processing varies within learners as L2 proficiency develops. One might also expect quite a bit of variability between learners as they progress along a developmental continuum. In other words, if we were to examine a set of learners' ERP responses at a given stage of L2 development, we might expect to see both quantitative and qualitative variability among learners. Given that ERP variability has been evidenced even in native speakers (Newman, Tremblay, Nichols, Neville, & Ullman, 2012; Osterhout, 1997; Pakulak & Neville, 2010)

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and that variability in L1 and in L2 may be obscured by examining only the grand mean effects in ERP data (Tanner, McLaughlin, Herschensohn, & Osterhout, 2013), several researchers have begun to employ correlational and regression-based analyses to explore what types of individual differences exist in L2 neurocognitive processing and what factors may account for such individual differences.

Emerging evidence has shown that ERP effects are subject to individual differences in L2 proficiency, verbal aptitude, and other cognitive factors (Batterink & Neville, 2013; Bond et al., 2011; Tanner, Inoue, & Osterhout, 2014; Tanner et al., 2013; White et al., 2012). In regard to L2 proficiency, research has generally confirmed that increasing proficiency is related to stronger P600s (Batterink & Neville, 2013; Tanner et al., 2013; Tanner et al., 2014; White et al., 2012). Tanner and colleagues (2013) examined individual differences in ERP responses across native-speakers of English enrolled in first-year and 300-level German classes (more advanced courses generally taken during the third year of language study) at a U.S. university and found that scores on a judgment task of subject-verb agreement were positively related to the magnitude of the P600 amplitude. In addition, a regression analysis showed that scores on the judgment task but not hours of instruction predicted the magnitude of the P600 effect, suggesting that proficiency rather than amount of exposure was the driving factor in the development of this nativelike processing effect. The positive relationship between the magnitude of the P600 effect and scores on judgment tasks has been replicated cross-linguistically for different grammatical forms, specifically for the English past tense (White et al., 2012) and for determiner-noun number agreement and word order, but not for subject-verb agreement, in "miniature" French, which is comprised of a subset of natural words and grammatical rules from French (Batterink & Neville, 2013, p. 939). Thus, it seems reasonable to predict that future research will also evidence such a relationship between the size of learners' P600 and their L2 proficiency, at least as reflected by scores on experimental judgment tasks.

The relationship between the amplitude of an ERP response and proficiency likely extends beyond the specific relationship between the P600 amplitude and judgment scores. Judgment scores have been shown to have a negative relationship with the amplitude of the N400 effect (Tanner et al., 2013). In addition, Tanner et al. (2014) reported a positive relationship between native Spanish speaker scores on a standardized English proficiency test, which did not specifically test knowledge of a target form, and the overall magnitude of learners' ERP response, regardless of whether it was a N400 or P600 effect, when processing English subject-verb agreement. Note, however, that there are slight differences between the relationship between ERP effects and proficiency as measured either by an experimental, judgment task or by an independent, objective measure of proficiency more generally. On the one hand, proficiency assessed by a judgment task that targets a particular L2 form was related to a smaller N400 effect and a larger P600 effect—a finding consistent with the model that L2 learners are likely to show no ERP response or N400s to grammatical processing at low levels of proficiency and P600s at intermediate stages and more advanced stages of proficiency (Steinhauer et al., 2009). On the other hand, proficiency assessed

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by an objective test of general L2 knowledge was related to larger ERP effects regardless of whether they are N400 or P600 effects. Future research is needed to flesh out the relationship between ERP responses and more constrained or more general measures of proficiency.

Individual differences in ERP effects appear to extend beyond L2 proficiency. A study of native English speaker processing of three types of L2 morphosyntactic forms in Spanish (i.e., subject-verb agreement, noun-adjective number agreement, and noun-adjective gender agreement) examined how ERP effects were related to verbal and nonverbal aptitude (Bond et al., 2011). Verbal aptitude was assessed using the short version of the Modern Language Aptitude Test (MLAT; Carroll & Sapon, 1959), including the MLAT3 Spelling Clues, which assesses vocabulary knowledge of English as well as sound-symbol association ability, MLAT4 Words in Sentences, which assesses grammatical sensitivity, and MLAT5 Paired Associates, which assesses rote learning ability. Nonverbal aptitude was assessed with Raven's Advanced Progressive Matrices (Raven's APM), which is a nonverbal assessment of general intelligence (Raven, 1965). Results showed a positive relationship between the P600 elicited by noun-adjective number agreement and both the MLAT4 and the composite MLAT scores. This relationship, however, may be limited to particular forms, given that no relationship was found between the MLAT and ERP responses to noun-adjective gender agreement or to subject-verb agreement. In addition, no evidence for a relationship between nonverbal aptitude and L2 processing emerged as no correlation existed between Raven's APM and processing of any of the grammatical forms. In all, these findings suggest that some aspects of verbal aptitude, grammatical sensitivity in particular, may be related to the magnitude of learners' ERP signatures for some target forms but do not provide evidence of relationship with nonverbal aptitude.

Behavioral L2 acquisition research has explored a multitude of individual differences that affect L2 development beyond aptitude (e.g., Dornyei & Skehan, 2003; Ehrman, Leaver, & Oxford, 2003), and ERP L2 research is beginning to explore whether several of these factors are related to neurocognitive processing. Beyond considering the relationship between the overall magnitude of ERP responses and proficiency, Tanner et al. (2014) also examined whether age of arrival in an L2-speaking environment, total length of residence, frequency of use, and motivation to speak like a native speaker were related to individuals' ERP responses to subject-verb agreement processing. None of these factors predicted the magnitude of the overall ERP response (as proficiency did), but age of arrival and motivation both predicted whether L2 speakers evidenced N400 or P600 responses. Specifically, the longer an L2 speaker had resided in an L2-speaking environment and the higher their motivation, the more likely they were to evidence a P600 effect rather than a N400 effect. These findings, taken together with other individual difference research, suggest that L2 neurocognitive processing is related to various linguistic and nonlinguistic factors, including specific and general L2 proficiency, verbal aptitude, length of residence in an L2-speaking environment, and motivation. Further research that uses measures of individual ERP responses rather than only grand average measures across learners will surely prove powerful in helping us to not only describe

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L2 neurocognitive processing but to also explain how and why such processing develops.

Effects of Learning Contexts on L2 Neurocognitive Processing

A final trend that has emerged in L2 ERP research in recent years is how neurocognitive processing may be affected by the context of learning. One question that has been posed by researchers interested in the context of learning is whether L2 learners can converge on nativelike processing responses through mere exposure to the L2. Mueller, Oberecker, and Friederici (2009) exposed German native speakers, who had no knowledge of Italian, to a nonadjacent dependency structure in L2 Italian by asking them to simply listen to short, correct sentences that contained the L2 structure. Exposure to the target structure alternated with testing blocks, where correct and incorrect sentences were presented auditorily and learners were asked to give a grammaticality judgment regarding each sentence. Native speakers of Italian also completed these tasks and evidenced both N400 and P600 effects to violation stimuli. The learner group, however, only evidenced a late N400 along with an anterior positivity (possibly a P3a). The researchers concluded that learners had only been able to employ lexical processing and general attentional processes, whereas the native speakers relied on grammatical processing. Citron, Oberecker, Friederici, and Mueller (2011) modified the research design of Mueller et al. (2009) to explore whether the alternation of the testing with the learning had impeded the development of the P600 effect in L2 learners. One group of learners received the same alternating design as in the original study and evidenced a N400 effect only. A second group of learners listened to the complete set of the learning stimuli before being asked to judge the grammaticality of the sentences. These learners evidenced a N400 but also evidenced a later positivity that was interpreted either as an attentional-based ERP component (P3a) or as a P600. Although all groups of learners in these studies evidenced behavioral gains and emerging ERP effects, the ERP effects did not clearly converge with that seen in native speakers. This finding could have been due in part to the fact that the native speakers presumably knew all the words and parsed the sentences for meaning whereas the learners did not know any of the vocabulary and must have only been able to parse the sound patterns presented to them. Thus the question about whether L2 can be learned through mere exposure remains open and should be addressed by future research that exposes learners to a novel L2 in a meaningful way.

A second question about whether context may influence how L2s are processed has focused on comparing the effects of different types of contexts. In behavioral research, different contexts, such as learning in a classroom as compared to learning in an immersion environment, have been shown to effect L2 development (Collentine & Freed, 2004; Freed, Segalowitz, & Dewey, 2004; Segalowitz & Freed, 2004). Similarly, a large body of research has examined whether L2 development is affected by different L2 training conditions, particularly looking at differential effects of explicit training, where rule explanation or direction to search for rules is provided, as compared to implicit training, where

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exposure to the L2 is provided in absence of rules or directions to search for rules (for reviews and meta-analyses of this research, see Norris & Ortega, 2000; Sanz & Morgan-Short, 2005; Spada & Tomita, 2010). Although explicit training often leads to advantages in L2 development, the explicit biases of many tests, among other limitations common to the research, limits the robustness of this conclusion. Indeed, when implicit training is provided in conjunction with task-essential practice, the advantages for explicit training can disappear (Sanz & Morgan-Short, 2004, 2005). Research on the neurocognition of L2 grammatical processing is only beginning to broach the topic of whether different learning contexts or types of training can affect not only L2 development but also the processing patterns that underlie such development (Batterink & Neville, 2013; Morgan-Short et al., in press; Morgan-Short et al., 2010; Morgan-Short, Finger, et al., 2012; Morgan-Short, Steinhauer, et al., 2012).

In order to elucidate whether L2 neurocognitive processing can be affected by training context, Morgan-Short and colleagues (Morgan-Short et al., 2010; Morgan-Short, Finger, et al., 2012; Morgan-Short, Steinhauer, et al., 2012) used an artificial language paradigm. The artificial language, Brocanto2—a modified version of Brocanto (Friederici et al., 2002), is a meaningful, productive artificial language whose syntactic rules conform to natural-language universals. Participants in these studies learned Brocanto2 in order to play a computer-based board game. After learning the rules of the game, participants received training on the artificial language itself under one of two conditions, each of which lasted about 13 minutes. Participants received either explicit training, which provided metalinguistic explanations and meaningful examples (phrases and sentences along with their corresponding game constellations and moves), or implicit training, which provided only meaningful examples of sentence-game constellation pairs. After training, participants engaged in practice with the language, which was identical for all learners and was comprised of both comprehension practice (listening to an aural Brocanto2 statement that referred to a move on the game board and then making that move) and production practice (seeing a move on the game board and then describing that move out loud). ERP data was collected at two points in the study—immediately after participants showed above chance performance on practice and again after all practice items (n = 880) had been completed. Participants engaged in a grammaticality judgment task of Brocanto2 sentences that contained either syntactic or morphosyntactic violations as the ERP data was collected.

Behavioral results on the judgment task showed no differences between the groups at low proficiency or at end-of-practice for morphosyntactic or for syntactic processing, although both groups were more accurate on judging syntactic violations as compared to morphosyntactic violations. There also were no group differences for the ERP responses to morphosyntactic stimuli at end-of-practice—both groups showed a N400 to gender agreement between nouns and adjectives and a P600 to gender agreement between determiners and nouns. There were, however, clear ERP differences in all other cases. For morphosyntactic processing at low proficiency, the implicit group showed a N400 for noun-adjective and determiner-noun gender agreement whereas the explicit group did not (Morgan-Short et al., 2010). For syntactic processing, the explicit group

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did not show any ERP effect at low proficiency but showed an anterior positivity (which is not a language-related component) followed by a P600 at end-of-practice. The implicit group showed a N400 at low proficiency and a bilateral AN followed by a P600 at end-of-practice, which is consistent with Steinhauer et al.'s (2009) predicted pattern of development. Morgan-Short, Steinhauer, et al. (2012) point out that only the implicitly trained learners evidenced the full biphasic ERP pattern often seen in native (morpho)syntactic processing. Interestingly, when tested 3–6 months later after no exposure to the artificial language, both groups retained their proficiency with the artificial language and showed more nativelike ERP responses after this amount of time of no exposure to the artificial language in that the explicit group lost the nonlanguage related anterior positivity and the implicit group's AN effect became left-lateralized (Morgan-Short, Finger, et al., 2012). The overall pattern of the results from these studies suggests that neurocognitive processing of L2 (morpho)syntax can be affected by the type of training a learner receives (although this is not necessarily so), even when behavioral differences are not evident, and that implicit training might be more effective in eliciting biphasic nativelike processing patterns.

Batterink and Neville (2013) also explored whether explicit or implicit training differentially affected neurocognitive processing for L2 (morpho)syntactic structures. Learners were exposed to a miniature version of French, which contained subject-verb agreement, number agreement between determiners and nouns, subject-verb agreement, and a fixed word order. Learners assigned to the explicit group were provided with a list and a description of the grammatical rules of mini-French and were informed that they would be tested on these rules at the end of training. Learners assigned to the implicit group were not provided with any rule explanation and were not told of the grammar test. All learners were asked to read 18 narratives in mini-French that were comprised of sentences paired with pictures and to responded to comprehension questions after each narrative. A total of 357 sentences were presented. After the training phrase, ERP data was collected as learners judged the grammaticality of mini-French sentences. ERP data was also collected for native speakers who evidenced P600 effects for each of the linguistic conditions as well as an AN for the subject-verb agreement condition. Explicitly and implicitly trained L2 learners showed behavioral differences on the judgment task with an advantage for the explicit group. This group also evidenced a P600 for each condition along with an additional posterior negativity for the subject-verb agreement. The implicit group was divided into two groups, one of which reached similarly high levels of proficiency and also showed P600 effects for all conditions, and another which showed intermediate levels of proficiency but did not evidence any significant ERP effects. Batterink and Neville concluded that the type of training affected learners' final level of proficiency but did not affect neurocognitive processing, at least when comparing learners at similar levels of proficiency. This conclusion was further supported by regression analyses that showed that training predicted proficiency but not ERP effects, but that proficiency predicted ERP effects.

These initial studies of the effect of type of training on the neurocognition of L2 processing have yielded both converging and diverging results. Both studies

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found that at higher levels of proficiency, both explicit and implicit training can lead to P600 effects: P600s for syntactic violations and (morpho)syntactic violations (i.e., article-noun gender agreement of Brocanto2; Morgan-Short et al., 2010) as well as P600s for syntactic and (morpho)syntactic violations in mini-French (Batterink & Neville, 2013). The results of the studies differed, however, in that Batterink and Neville (2013) did not find ERP effects for a group of implicitly trained learners who did not reach high levels of proficiency whereas the implicitly trained learners in the Morgan-Short et al. studies evidenced N400 effects at low proficiency. In addition, Morgan-Short and colleagues found an AN effect in implicitly but not explicitly trained learners, suggesting that they could uniquely arrive at a biphasic AN and P600 effect that has been evidenced in native speakers of natural languages. Several methodological differences between the studies could account for the differences in the findings. For example, the amount of exposure to the L2 through practice was greater in the Morgan-Short et al. studies as compared to the Batterink and Neville study. If additional practice had been provided in Batterink and Neville, more implicit learners might have achieved high levels of proficiency and evidenced P600 effects. Another important difference is that learners in the Batterink and Neville study only engaged in comprehension practice with the L2 whereas learners in Morgan-Short et al. studies engaged in both comprehension and production practice. The production practice in these studies might have engaged the learners more actively in using the grammatical structures for a meaningful purpose (Swain, 1993; Swain & Lapkin, 1995), which might have led to the N400 effect at low proficiency and the AN at high proficiency. Many other differences between the studies exist (e.g., aural versus written presentation of the L2), so it is not possible to determine what was responsible for the differing results. The results, however, clearly warrant further investigation into the effects of context and training on L2 neurocognitive processing.

CONCLUSION

This article reviewed L2 ERP research from the past five years (2008–2013). Four major trends in the research have been identified and discussed. First, longitudinal L2 ERP research has demonstrated that L2 neurocognitive processing changes qualitatively with time suggesting that there are discrete stages of L2 development. Second, research that examines how processing may be affected by L1-L2 similarity has shown that L2 learners can evidence nativelike ERP effects for L2 grammatical features that are present in their L1 as well as for features that are unique to their L2. Interestingly though, L2 learners show more difficulty in processing features that are present in their L1 but that are instantiated differently in their L2. Third, emerging research has revealed that individual differences in ERPs can be accounted for by proficiency, some aspects of verbal aptitude, and other factors such as motivation and length of residence. Fourth, recent empirical studies have shown that explicit and implicit training contexts can lead to nativelike ERP effects at high levels of proficiency, but that implicit contexts may lead to the

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development of a fuller nativelike processing signature, at least for syntactic processing. These patterns of findings have significantly moved forward our understanding of the neurocognitive processing on L2, in part because they have been informed both by research in cognitive neuroscience as well as by research in the field of second language acquisition. With continued interdisciplinary approaches and sophisticated research designs, the potential of L2 ERP results to inform central questions of second language acquisition is great indeed.

NOTES

1 The term *(morpho)syntax* will be used to refer to morphosyntax and syntax simultaneously.
2 The terms AN and LAN will be used interchangeably in the current article. Generally the term used by the authors of original research articles will be adopted when describing those particular articles.

ANNOTATED BIBLIOGRAPHY

Gillon Dowens, M., Vergara, M., Barber, H. A., & Carreiras, M. (2010). Morphosyntactic processing in late second-language learners. *Journal of Cognitive Neuroscience*, *22*, 1870–1887.

This article provides a comprehensive report of gender and number agreement processing in L2 as compared to native speakers. The findings demonstrate the complexity of L2 processing in that learners evidence a fully nativelike response to both number and gender agreement between determiners and nouns but only evidence a partially nativelike response to number and gender agreement between nouns and adjectives. The pattern of findings suggests that research must consider multiple factors (e.g., L1-L2 similarity as well as linguistic structure), in order to obtain a nuanced understanding of L2 neurocognitive processing.

McLaughlin, J., Tanner, D., Pitkänen, I., Frenck-Mestre, C., Inoue, K., Valentine, G., & Osterhout, L. (2010). Brain potentials reveal discrete stages of L2 grammatical learning. *Language Learning*, *60*, 123–150.

This report of a series of L2 ERP studies is significant because it provides evidence that the group-averaged ERP signal is not necessarily representative of individual processing and that subgroups of learners who show qualitatively different processing signatures can be identified. In addition, the data reported in this article shows that the same linguistic stimuli can elicit different ERP effects within learners over time. This article is significant in that it serves as an impetus for carrying out longitudinal research and for exploring individual differences within groups of L2 learners.

Steinhauer, K., White, E. J., & Drury, J. E. (2009). Temporal dynamics of late second language acquisition: Evidence from event-related brain potentials. *Second Language Research*, *25*, 13–41.

This review of L2 ERP research proposes a model of neurocognitive L2 development based on proficiency, with a series of qualitative and quantitative changes in learners' ERP response to (morpho)syntactic processing. The proposal

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serves as an impetus for longitudinal L2 ERP research and has important implications for neurocognitive theories of L2 acquisition.

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