Implicit and Explicit Second Language Training Recruit Common Neural Mechanisms for Syntactic Processing

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Abstract

■ In contrast to native language acquisition, adult second-language (L2) acquisition occurs under highly variable learning conditions. Although most adults acquire their L2 at least partially through explicit instruction, as in a classroom setting, many others acquire their L2 primarily through implicit exposure, as is typical of an immersion environment. Whether these differences in acquisition environment play a role in determining the neural mechanisms that are ultimately recruited to process L2 grammar has not been well characterized. This study investigated this issue by comparing the ERP response to novel L2 syntactic rules acquired under conditions of implicit exposure and explicit instruction, using a novel laboratory language-learning paradigm. Native speakers tested on these stimuli showed a biphasic response to syntactic violations, consisting of an earlier negativity followed by a later P600 effect. After merely an hour of training, both implicitly and explicitly trained learners who were capable of detecting grammatical violations also elicited P600 effects. In contrast, learners who were unable to discriminate between grammatically correct and incorrect sentences did not show significant P600 effects. The magnitude of the P600 effect was found to correlate with learners' behavioral proficiency. Behavioral measures revealed that successful learners from both the implicit and explicit groups gained explicit, verbalizable knowledge about the L2 grammar rules. Taken together, these results indicate that late, controlled mechanisms indexed by the P600 play a crucial role in processing a late-learned L2 grammar, regardless of training condition. These findings underscore the remarkable plasticity of later, attention-dependent processes and their importance in lifelong learning. ■

INTRODUCTION

In contrast to native language acquisition, which takes place in the natural social setting of a child's first years of life, adult second-language (L2) acquisition occurs under highly variable conditions. Some adults, such as immigrants to a foreign country, may acquire an L2 primarily through immersion, in the absence of any formal schooling. Many other adults acquire their L2 largely through formal instruction, as in a classroom setting. Even within the classroom, L2 learners may experience a substantially different learning environment, with instruction ranging from conversation-based approaches that emphasize meaning and communication to more traditional methods that focus on teaching metalinguistic grammar rules (Mitchell, 2000; Celce-Murcia, 1991; Long, 1991). An important dimension that characterizes these environmental differences is the degree to which L2 input is implicit versus explicit. In an implicit L2 environment, learners engage with the target language but are not provided with explanations of L2 grammar rules or otherwise asked to attend to these rules. In contrast, in an explicit L2 environment, learners are provided with metalinguistic grammar rules or instructed to attend to particular forms and try to arrive at metalinguistic generalizations of their own (Norris & Ortega, 2000; DeKeyser, 1995). Given how variable L2 acquisition environments are, a basic research question is whether differences in input conditions (i.e., implicit or explicit) play a role in specifying the neural mechanisms that are recruited for L2 processing. A second, applied issue is whether implicit exposure or explicit training is optimal for L2 learning. Although this topic has been one of the most hotly debated in the fields of L2 acquisition research and applied linguistics (e.g., Ellis, 2008; Norris & Ortega, 2000, 2001; DeKeyser, 1995; Krashen, 1982), it has been largely ignored by previous neurocognitive studies of language.

Most previous investigations on the neurobiology of L2 processing have focused on bilinguals who acquired their L2 in school, presumably largely through explicit instruction (e.g., Pakulak & Neville, 2011; Rossi, Gugler, Friederici, & Hahne, 2006; Ojima, Nakata, & Kakigi, 2005; Tokowicz & MacWhinney, 2005; McLaughlin, Osterhout, & Kim, 2004; Hahne, 2001; Hahne & Friederici, 2001; Perani et al., 1998; Dehaene et al., 1997; Perani et al., 1996). Relatively few studies have included bilinguals who likely acquired their L2 in more implicit environments, having

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been exposed to their L2 before reaching school age (Wartenburger et al., 2003; Chee, Tan, & Thiel, 1999; Weber-Fox & Neville, 1996), and of those that have age of acquisition and learning environment tend to be confounded. Thus, very little is known about the neural mechanisms that are recruited as a consequence of implicit L2 exposure, including the degree to which these mechanisms are dissociable from those supporting explicit L2 learning. Although this question is beginning to gain more interest (Morgan-Short, Finger, Grey, & Ullman, 2012; Morgan-Short, Steinhauer, Sanz, & Ullman, 2012; Morgan-Short, Sanz, Steinhauer, & Ullman, 2010), overall, the lack of evidence on this topic stands in contrast to other parameters of L2 learning, such as age of acquisition, proficiency, and L1–L2 similarity, which have been much more thoroughly investigated (e.g., Foucart & Frenck-Mestre, 2011; Pakulak & Neville, 2011; Abutalebi, 2008; Sabourin & Stowe, 2008; Rossi et al., 2006; Tokowicz & MacWhinney, 2005; Wartenburger et al., 2003; Chee et al., 1999; Perani et al., 1998; Weber-Fox & Neville, 1996). This is somewhat surprising, as neurobiological research in this area has the potential not only to yield basic evidence concerning human learning mechanisms but also to inform L2 teaching practices.

Electrophysiology of L2 Processing

One major goal of neurobiological studies of L2 processing is to characterize how delays in acquisition impact the neural mechanisms underlying language processing. As a sensitive index of real-time language processing, ERPs have proven to be especially well suited in investigating this topic. ERP studies of L2 processing have shown that the syntactic subsystem is particularly vulnerable to delays in acquisition. In contrast to semantic processing, for example, which is indexed by qualitatively similar N400 effects in both native speakers and late L2 learners (Ojima et al., 2005; McLaughlin et al., 2004; Hahne, 2001; Hahne & Friederici, 2001; Weber-Fox & Neville, 1996), syntactic processing usually elicits qualitatively different ERP effects in L1 and L2 speakers.

In native speakers, the hallmark ERP pattern elicited by grammatical violations is a biphasic response, consisting of an early negativity typically maximal over the left anterior scalp (termed as the LAN), followed by a later positivity (termed as the P600; e.g., Friederici, Pfeifer, & Hahne, 1993; Neville, Nicol, Barss, Forster, & Garrett, 1991). The LAN is unaffected by task and probability manipulations (Hahne & Friederici, 1999, 2002; Coulson, King, & Kutas, 1998; Gunter, Stowe, & Mulder, 1997) and thus appears to be at least relatively automatic. This component is thought to index more automatic processes associated with syntactic processing, such as the building of an initial syntactic structure based on word category information (Friederici, 1995, 2002). In contrast, the P600 varies as a function of violation probability and task requirements (Hahne & Friederici, 1999, 2002; Gunter & Friederici, 1999; Coulson et al., 1998; Gunter et al., 1997) and is thus thought to be controlled in nature. The P600 has been proposed to index the reanalysis and repair of syntactic structure, controlled, attention-dependent processes that are triggered only after initial parsing of the incoming sentence fails (Friederici, 1995, 2002; Hagoort & Brown, 2000).

In contrast to native speakers, LAN and P600 effects in L2 speakers appear to be quite variable, with different studies reporting different patterns of results. L2 speakers have been reported to elicit neither a LAN nor a P600 (Hahne & Friederici, 2001), both a LAN and a P600 (Rossi et al., 2006), a LAN in the absence of a P600 (Ojima et al., 2005), or perhaps most commonly, a P600 effect with no preceding LAN (Dowens, Guo, Barber, & Carreiras, 2011; Pakulak & Neville, 2011; Kotz, Holcomb, & Osterhout, 2008; Rossi et al., 2006; Hahne, 2001). Although conflicting evidence also exists (e.g., Dowens, Vergara, Barber, & Carreiras, 2009; Hahne, Mueller, & Clahsen, 2006; Rossi et al., 2006), in general, these results suggest that late learners rely on different neural mechanisms from native speakers when processing grammar. The LAN in particular appears to be especially impacted by delays in acquisition, suggesting that earlier, more automatic mechanisms underlying grammatical processing in native speakers may not be readily available to late learners.

Although there appear to be qualitative differences in the neural mechanisms supporting grammar between native speakers and late learners, recent ERP studies using longitudinal or learning-based experimental designs have highlighted that the certain aspects of the neural system underlying grammatical processing nonetheless show remarkable plasticity throughout life. For example, Osterhout and colleagues tracked English-speaking students progressing through their first year of a foreign language course (McLaughlin et al., 2010; Osterhout et al., 2008). These students showed a P600 effect to verb agreement violations after only 26 weeks of classroom instruction, and this effect emerged within an even shorter period—after only 16 weeks—in faster learners.

Even more rapid changes have been found in training studies. Mueller, Hahne, Fujii, and Friederici (2005) trained German speakers on a miniature version of Japanese (termed as “mini-Nihongo”) using an audio–visual computer game in which participants learned the meaning and structure of mini-Nihongo through trial-and-error learning, guided by computerized feedback. After training (between 4 and 10 hr), word category and case violations elicited robust P600s in learners; these same errors also elicited P600s in a control group of native Japanese speakers, as well as an earlier anterior negativity in the word category violation condition and an N400 in the case violation condition. The same group of learners was tested approximately 6 months later, after completing

1–3 hr of refreshment training, and showed a P600 effect to nominative and accusative case violations, whereas native Japanese speakers displayed an N400–P600 effect to both of these violation types (Mueller, Hirotani, & Friederici, 2007). In a third mini-Nihongo study, Mueller, Girgsdies, and Friederici (2008) trained an additional group of participants on case agreement in mini-Nihongo, using a computerized training game that taught participants to correctly build and analyze the syntactic structure of mini-Nihongo without reference to semantic information. Upon completion of training (between 2 and 8 hr), semantic-free learners showed both an N400-like negativity and a P600 to case violations, resembling the pattern elicited by native Japanese speakers. In yet another study, Davidson and Indefrey (2008) explicitly taught native Dutch speakers the rules of German adjective declension and gender agreement using metalinguistic grammar rules and a feedback-based training task that took approximately 20 min. Learners were tested 1 week after training and showed a P600 response to declension violations, although not to gender violations; native German speakers showed significant P600 effects to both of these violation types.

Finally, Friederici, Steinhauer, and Pfeifer (2002) trained learners on a miniature artificial language called Brocanto using a computerized board game. Participants playing this game communicated all their moves verbally in Brocanto and received computerized feedback and corrections on any incorrect utterances. After training, learners showed an early anterior negativity, maximal over midline electrodes, followed by a posterior negativity and a P600 effect to violations in Brocanto. Although the absence of a native speaker control group makes it difficult to assess the "nativeness" of this response, these results suggest that, given a linguistic system with a very limited vocabulary and set of rules, early, more automatic mechanisms may be recruited for syntactic processing. Morgan-Short, Steinhauer, et al. (2012) used a modified version of the Brocanto training paradigm to examine the effects of implicit versus explicit language training. In the explicit training condition, participants were provided with metalinguistic explanations of the rules of Brocanto, whereas in the implicit training condition, participants were exposed to a larger number of exemplar sentences with no metalinguistic explanations provided. All participants then played a computerized board game, similar to that used by Friederici and colleagues, in which correct/incorrect feedback was provided. After three sessions of training, both groups showed P600 effects to word order violations in the artificial language. The explicit group also showed an additional anterior positivity between 350- and 700-msec poststimulus, whereas the implicit group showed an extended anterior negativity between 150- and 900-msec poststimulus. These results were interpreted as evidence that type of L2 training may influence the neural mechanisms recruited to process the L2.

Taken together, findings from longitudinal and learning studies suggest that rapid neural changes can accompany L2 grammar learning, even during very early stages. In particular, the P600 appears to be a sensitive marker of syntactic learning. However, similar to cross-sectional L2 studies, these learning-based studies have mainly focused on the results of more explicit types of training: Many of these previous training paradigms have included explicit instruction of metalinguistic grammar rules (explicit group in Morgan-Short, Steinhauer, et al., 2012; McLaughlin et al., 2010; Davidson & Indefrey, 2008; Osterhout et al., 2008), and even studies using more naturalistic or implicit training methods have employed training tasks that require knowledge of L2 grammar and that provide feedback for incorrect responses (implicit group in Morgan-Short, Steinhauer, et al., 2012; Mueller et al., 2005, 2007, 2008; Friederici et al., 2002).

In the present study, we examined the neural mechanisms recruited for L2 processing as a consequence of implicit training by using a novel laboratory language-learning task in which the grammatical structure of the L2 was incidental to the task at hand. We also investigated the extent to which these mechanisms are common to or dissociable from those recruited by explicitly trained learners and native speakers. Native English speakers were briefly immersed in a miniature unknown language (French) and tasked with comprehending the language to the best of their ability. In an implicit group, no mention was made of grammar, whereas in an explicit group, participants received formal instruction on the underlying grammatical rules before exposure began. Following training, learners' ERP responses to three types of syntactic violations were measured. We also examined a group of native French speakers using the same paradigm to explore whether learners recruit some of the same language-processing mechanisms as those employed by native speakers of the same language.

Results yielded from this study should be capable of distinguishing between at least two alternative hypotheses. One possibility is that L2 grammar acquired through implicit exposure may be mediated by a similar set of neural mechanisms as L2 grammar acquired through explicit instruction. In this case, implicitly trained participants should demonstrate P600 effects to syntactic violations after training, as has been found in explicitly trained participants. Another possibility is that the way through which an L2 is acquired impacts the ultimate neural representation of that language, at least at beginning levels of proficiency. Under this scenario, implicitly trained participants should show one or more ERP violation effects that are qualitatively distinct from the P600, either in latency or in distribution. Finally, by including a group of native speakers, this study aimed to examine the extent to which mechanisms recruited by nonnative learners and native speakers overlap or are dissociable. On the basis of previous literature, we hypothesized that a LAN would be present only in native speakers, whereas a P600 effect would be present both in native speakers as well as in explicitly trained learners.

METHODS

Participants

Sixty-seven native English speakers (33 women, mean age = 21.6 years) were recruited at the University of Oregon to participate in the experiment. All participants were carefully screened to ensure that they had never studied French or another Romance language in school or been otherwise exposed to a Romance language to a significant degree. Participants were randomly assigned to the implicit training condition ($n = 44$) or the explicit training condition ($n = 23$). (Because behavioral performance of implicitly trained participants was highly variable, a larger number of participants were assigned to the implicit condition, allowing for subsequent division based on proficiency level.) All participants were right-handed. Implicit and explicit groups did not significantly differ in terms of age, sex, number of L2s studied, years of L2 study, or age of first exposure to an L2 (all p values $> .2$; see Table 1).

In addition, 24 native French speakers (21 women, mean age = 26.4 years) were also recruited and run on the same paradigm to directly compare learners' ERP effects to those elicited by native speakers. French-speaking participants' countries of origin included France ($n = 18$), Cameroon ($n = 3$), Belgium ($n = 1$), Burkina Faso ($n = 1$), and Italy ($n = 1$). All French speakers were born to at least one native French-speaking parent, spoke French in the home from infancy, and considered French to be their native language. Four French-speaking participants were left-handed.

All participants had normal or corrected-to-normal vision and had no history of neurological problems. Six participants in total (three from the implicit group, two from the explicit group, and one native French speaker) were excluded from EEG analyses because of excessive EEG artifact. Two additional native French speakers were excluded from all analyses because of poor performance on the grammaticality judgment task (below 66% accuracy). All participants received either payment or course credit for their time.

Stimuli

Training Task

In the initial training paradigm, short narratives made up of simple French sentences that conformed to the same subject–verb–object (SVO) grammatical structure were presented: Each sentence contained five words, consisting of an article, noun, direct verb, a second article, and a second noun. This "miniature" French language was intentionally designed to consist of only a limited number of words and a small set of syntactic rules to facilitate learning. Only three articles (definite articles in the masculine singular, feminine singular, and plural forms) and two verb conjugations (third-person singular and plural) were used throughout the training paradigm. A small pool of open-class words (98 nouns and 56 verbs) were frequently repeated across sentences and narratives (mean number of repetitions = 7). Nouns generally referred to people or common, everyday objects in the environment (e.g., boy, girl, dog, cat, bicycle, cookie). Verbs followed the regular French "-er" infinitive conjugation pattern and generally referred to simple actions that could be easily illustrated (e.g., eat, throw, catch). All sentences conformed to three grammatical rules: (a) article–noun agreement (e.g., *le garçon*/*les garçons* = "the$_{sing}$ boy/the$_{plural}$ boys), which shares surface similarities with demonstrative pronoun–noun agreement in learners' L1 (e.g., "that boy/those boys"); (b) subject–verb agreement (e.g., *le garçon mange*/*les garçons mangent* = "the boy eats/the boys eat"), which does not share surface similarities with verb agreement in learners' L1; and (c) word order (e.g., *Le garçon mange le gâteau*), which conforms to the same SVO structure that is dominant in learners' L1, English.

To illustrate meaning, each sentence was paired with an accompanying picture. The picture was presented for 3 sec before the onset of the sentence. The picture was then faded out to reduce its visibility, and a fixation box was presented below the faded image. Next, the sentence

Table 1. Participant Demographics and Language Background by Group

	Implicit Group	*Explicit Group*	*Statistical Difference between Groups*
Sex	22 M/22 F	12 M/11 F	$\chi^2(1) = 0.29, p = .87$
Age (years)	21.3 (2.6)	22.1 (4.1)	$t(65) = 0.90, p = .37$
Number of L2s studied	0.9 (0.6)	1.1 (0.8)	$t(65) = 0.88, p = .38$
Years of L2 study	3.2 (3.4)	4.2 (3.8)	$t(65) = 1.45, p = .26$
Age of first exposure to an L2[a]	13.4 (4.1)	13.5 (4.7)	$t(52) = 0.056, p = .96$

Standard deviations are provided in parentheses.

[a]Includes only participants who previously learned an L2.

was presented one word at a time in the center of the fixation box; each word had a duration of 400 msec with a 200-msec ISI. Both the faded image and fixation box stayed on the screen until 1500 msec after the onset of the final word. To ensure adequate attention, two alternative multiple-choice comprehension questions were presented after every narrative. The questions were in English, although the possible responses were French nouns. A total of 357 sentences, comprising 18 narratives, were presented. This initial training phase lasted approximately 1 hr. Examples of the sentences and pictures used in training are shown in Figure 1A.

Grammaticality Judgment Task

In the subsequent grammaticality judgment task, new sentences that either conformed to or violated the grammatical rules established during the initial training phase were displayed. These sentences consisted of new verbs and nouns to which participants had not been previously exposed during training. Articles and verb conjugation endings did not differ from the forms that had been used in the training paradigm. As illustrated in Figure 1B, three grammatical constructions were tested: article–noun agreement, subject–verb agreement, and word order. Article–noun violations comprised number agreement mismatches between articles and nouns. Subject–verb violations consisted of incorrectly inflected verbs that disagreed in number with the subject. Word order violations were made up of sentences in which an article was immediately followed by an inflected third-person-plural verb instead of a noun (*Les mangent** = "the$_{plural}$ eat") or in which a noun was immediately followed by another noun instead of a verb (*Les livres garçons* = "the$_{plural}$ books boys"). Each sentence containing a grammatical violation was matched with a grammatically correct control sentence. Sentences were designed so that both preceding sentence contexts and critical words were identical across canonical and violation conditions. Participants saw both the canonical and violation versions of each sentence. Sentences were presented in randomized order with the constraint that the violation and canonical versions of a given sentence appeared no closer than three sentences together. A total of 240 sentences were presented, with 40 sentences in each of the six conditions (article–noun violation, article–noun canonical control, subject–verb violation, subject–verb canonical control, word order violation, word order canonical control).

Each sentence was preceded by a fixation box, which was presented 1000 msec before the first word and remained on the screen until the offset of the final word in the sentence. Sentences were displayed one word at a time in the center of the fixation box (duration = 400 msec, ISI = 200 msec). After each sentence, a cue ("Right/Wrong?") was presented and remained on the screen until the participant's response. All stimuli in both the training task and the grammaticality judgment task were presented on a computer monitor placed approximately 140 cm away from the participant.

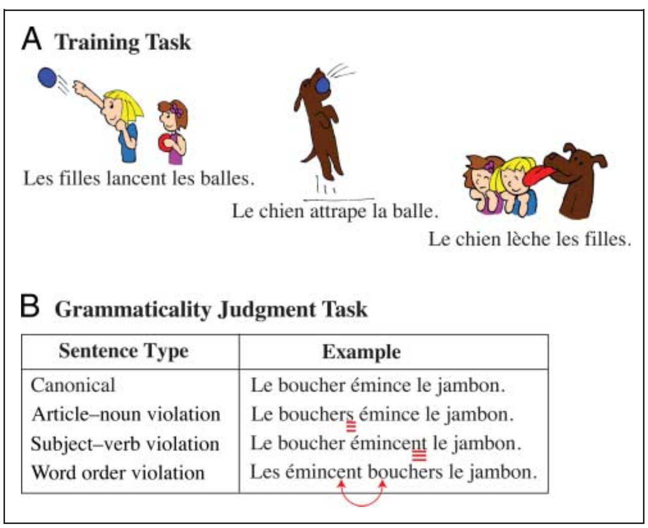


Figure 1. Stimuli used in the (A) training task and (B) grammaticality judgment task. (A) In the training task, participants were presented with short narratives made up of simple sentences, paired with pictures to illustrate meaning. (B) Examples of syntactic violations tested in the grammaticality judgment task.

Procedure

Participants were tested individually in a single 2.5-hr session. After application of an electrode cap, participants were seated in a comfortable chair in a dimly lit, acoustically and electrically shielded booth. Participants assigned to the implicit group were told that they would be reading stories in a foreign language that were paired with pictures to aid comprehension. They were instructed to read the sentences carefully, to follow each story as well as they could, and to learn as many of the new foreign language words as possible. No mention was made of grammar or of the upcoming grammaticality judgment task. Participants assigned to the explicit group were also informed that they would be reading stories in a foreign language. However, before the training task began, they were given a sheet of paper with a list and description of each of the grammatical rules of mini-French. They were told to read these rules carefully and informed that they would be tested on these rules in the second part of the experiment. They were also instructed that all of the sentences in the exposure task would conform to these grammatical rules and were asked to focus on both the grammar and meaning of these sentences. The experimenter also provided a brief verbal description of each grammatical rule and addressed any questions that the participant had about the rules. Participants in the explicit group typically finished the explicit instruction portion of the training within a few minutes (<5), whereas the main exposure task took approximately 1 hr to complete.

The grammaticality judgment task was performed immediately after the training task. Participants in the implicit group were told that all of the sentences that they had read were examples of grammatically correct sentences and that, based on the knowledge that they had acquired during the training phase, they would now need to decide whether new sentences in the same language were grammatically correct or incorrect. Participants in the explicit group were instructed to judge whether each sentence was correct or incorrect based on the rules that they had learned in the training phase. The grammaticality judgment task took approximately 40 min.

Following the grammaticality judgment task, participants completed a paper-and-pencil questionnaire designed to measure their explicit knowledge of the three grammatical rules under investigation. The questionnaire included 14 sentences (three grammatical violations of each rule type as well as two grammatical sentences) that had previously appeared on the grammaticality judgment task. Participants were asked to indicate whether each sentence was grammatically correct or incorrect, to correct any grammatical violations that they found, and to describe the grammatical rule that had been violated for each sentence. Each question was coded as "1" if the participant provided the appropriate correction as well as a reasonable explanation of which grammatical rule had been broken (e.g., given a sentence containing "le bouchers*," participant correctly replaces "le" with "les" and provides an explanation such as "needs an 's'" or "article needs to be pluralized because noun is pluralized"). If the participant was not able to provide the appropriate correction or to successfully verbalize which rule had been broken, the question was coded as 0. Each rule was scored separately, out of a maximum of three points.

In a final interview, participants were asked whether they had attended primarily to vocabulary or grammar during the training task, how they thought they had performed on the grammaticality judgment task, and whether they could describe any of the grammatical rules of mini-French.

Native French speakers were run through the same paradigm as the learners. They were instructed simply to read the sentences in the training task for comprehension and to judge each sentence in the grammaticality judgment task as grammatically correct or incorrect.

ERP Recording and Analysis

EEG data were collected throughout the training task and the grammaticality judgment task; only data from the grammaticality judgment task are reported here. EEG was recorded at a sampling rate of 512 Hz from 64 Ag–AgCl-tipped electrodes attached to an electrode cap using the 10–20 system. Recordings were made with the Active-Two system (Biosemi, Amsterdam, Netherlands), which does not require impedance measurements, an online reference, or gain adjustments. Additional electrodes were placed on the left and right mastoid, at the outer canthi of both eyes, and below the right eye. Scalp signals were recorded relative to the Common Mode Sense active electrode and then rereferenced off-line to the algebraic average of the left and right mastoid. Left and right horizontal eye channels were rereferenced to one another, and the vertical eye channel was rereferenced to FP1.

ERP analyses were carried out using EEGLAB (Delorme & Makeig, 2004). All ERP analyses include only those trials for which a correct grammaticality judgment was made. Data were band-pass filtered from 0.1 to 40 Hz. Next, epochs time-locked to critical word onset were extracted from −100 to 1500 msec. Trials containing large or paroxysmal artifacts or movement artifacts were identified by visual inspection and removed from further analysis. Data were then submitted to an independent component analysis (ICA) using the extended runica routine of EEGLAB software. Ocular artifacts were identified from IC scalp topographies and the component time series and removed, and ICA-cleaned data were then subjected to a manual artifact correction step to detect any residual or atypical ocular artifacts not removed completely with ICA. The data were then submitted to a second cleaning step, which involved low-pass filtering the data at 20 Hz, running the extended runica routine for the second time, and removing all components in the second ICA decomposition identified as artifactual. For a subset of participants (n = 26), one or more channels were identified as bad, excluded from all ICA decompositions, and later interpolated using EEGLAB's pop_interp function. Epochs were averaged to the onset of the critical word and plotted to 1000-msec poststimulus, with a 100-msec baseline. Only participants who had a sufficient number of correct artifact-free trials in both canonical and violation bins (≥8 trials) were included in the final grand averages. This criterion was based on visual inspection of the individual averages. The number of participants contributing to each average is shown in Table 2.

On the basis of visual inspection of the waveforms and on a priori hypotheses from previous studies, two time windows for statistical analyses were selected for each condition. The LAN time window was selected as 300–400 msec poststimulus for the noun and verb condition and 300–450 msec for the word order condition, and the P600 time window was selected from 500–900 msec poststimulus for all conditions. Waveforms were quantified by measuring mean voltages within the selected latency windows, relative to a 100-msec prestimulus baseline. To increase the signal-to-noise ratio over the 64 channels, amplitudes were averaged across neighboring electrodes to form nine channel groups of interest (left anterior region: AF7, AF3, F7, F5, F3; left central region: FT7, FC5, FC3, T7, C5, C3; left posterior region: TP7, CP5, CP3, P7, P5, P3, PO7, PO3; midline anterior region: AFZ, F1, FZ, F2; midline central region: FC1, FCZ, FC2, C1, CZ, C2; midline posterior region: CP1, CPZ, CP2, P1, PZ, P2, POZ; right anterior region: AF4, AF8, F4, F6, F8;

Table 2. Number of Participants Contributing to Each Average

Violation Condition	*Native French Speakers*	*Implicit, High Proficiency*	*Explicit, High Proficiency*	*Implicit, Low Proficiency*
Noun	21	18	21	21
Word order	21	18	18	19
Verb	21	11	19	19

right central region: FC4, FC6, FT8, C4, C6, T8; right posterior region: CP4, CP6, TP8, P4, P6, P8, PO4, PO8).

To examine ERP group averages as a function of proficiency, both explicit and implicit participants were divided into high-proficiency and low-proficiency groups for each violation condition (noun violation, verb violation, and word order violation) based on their performance on the grammaticality judgment task (high proficiency: $d' \geq 1.0$, low proficiency: $d' < 1.0$). Because very few explicit participants failed to achieve d' scores of at least 1.0 for any violation conditions ($n_{\text{noun}} = 0$, $n_{\text{verb}} = 3$, $n_{\text{word order}} = 2$), four groups were formed for group analyses: implicit high proficiency, implicit low proficiency, explicit high proficiency, and native French speakers.

For group analyses, mean voltage amplitudes for each time window and each grammatical violation condition (noun violation, verb violation, and word order violation) in the nine channel groups of interest were separately analyzed using repeated-measure ANOVAs, including congruency (canonical, violation), column (left hemisphere, midline, right hemisphere), and anterior/posterior (anterior, central, posterior) as within-subject factors and group (implicit high proficiency, implicit low proficiency, explicit high proficiency, and native French speakers) as a between-subject factor. Where significant group differences were found, effects within each group were quantified in follow-up analyses using separate ANOVAs for each group. To better evaluate nonsignificant results, confidence intervals and effect sizes (η^2) are reported as a complement to p values in all group contrasts (Colegrave & Ruxton, 2003). For distributional group comparisons, data were normalized according to the procedure recommended by McCarthy and Wood (1985) to account for amplitude differences. Greenhouse–Geisser corrections are reported for factors with more than two levels.

As a more sensitive measure of the relationship between proficiency (d' scores) and ERP amplitude in all learners, zero-order Pearson's correlations were calculated between individual d' scores and individual average difference amplitudes (violation–canonical) in the nine channels groups during the P600 time window, for each of the violation conditions. Similarly, to examine whether training (implicit vs. explicit) was a significant predictor of P600 amplitude, zero-order point-biserial correlations were calculated between training and P600 amplitude in the nine channel groups for each of the violation conditions. Finally, to investigate the potentially interconnected relationships between training, proficiency, and P600 amplitude, we used the Hayes and Preacher mediation procedure, entering training as the independent variable, P600 amplitude as the dependent variable, and proficiency as a possible mediator (Preacher & Hayes, 2008). Bootstrapping (with 5,000 replications) was used to calculate bias-corrected standard errors of the indirect paths.

RESULTS

Behavioral Results

Training Task

All learners performed well on the comprehension task of the training paradigm (mean percentage correct = 94%, *SD* = 5%), indicating that they paid adequate attention to the presented stimuli. As expected, there were no differences in comprehension scores between implicitly and explicitly trained participants ($t(65) = 0.61$, $p = .54$), indicating that both groups attended to the task equally well. In contrast, native French speakers achieved significantly higher comprehension scores than learners ($t(89) = 5.03$, $p < .001$; mean percentage correct = 99%).

Of the implicitly trained participants, the majority (73%) reported attending only to vocabulary during the training paradigm in a postexperiment interview, whereas a smaller subset (27%) reported attending to grammar as well as vocabulary. Comprehension scores of participants who attended only vocabulary (mean = 94%, *SD* = 5%) were not significantly different from those participants who attended to both grammar and vocabulary (mean = 95%, *SD* = 5%; $t(42) = 0.58$, $p = .57$).

Grammaticality Judgment Task

Implicitly trained participants ($n = 44$) performed significantly more poorly than explicitly trained participants ($n = 23$) on the grammaticality judgment task ($t(65) = 7.59$, $p < .001$). The mean d' score for implicitly trained participants across all grammatical violation types was 0.94 (*SD* = 0.99), corresponding to 64% accuracy, whereas the mean d' score for explicitly trained participants was 3.0 (*SD* = 1.2, 89% accuracy). Both implicitly and explicitly trained participants scored significantly above chance (defined as 50% correct; implicit group: $t(43) = 2461$,

$p < .001$; explicit group: $t(22) = 1881$, $p < .001$). As shown in Figure 2, grammaticality judgment performance was highly variable across participants, with scores ranging from at-chance to ceiling levels (range in d' scores = −0.1 to 4.52, range in accuracy = 48% to 99%).

Of the implicitly trained participants, those who reported attending to grammar during the initial learning period performed significantly better ($d' = 1.6$ [SD = 1.37]) on the subsequent grammaticality judgment task than those who had attended only to vocabulary (d' = 0.69 [SD = 0.67]; $t(42) = 2.92$, $p = .006$).

Across all learners, participants performed significantly more poorly on verb agreement judgments (mean d' score = 1.4) than on the other two conditions (omnibus ANOVA: $F(2, 132) = 7.62$, $p = .001$; contrast: $F(1, 66) = 11.0$, $p = .001$). In contrast, performance on the grammaticality judgment task was similar for noun agreement (mean d' score = 1.7) and word order sentences (mean d' score = 1.8; contrast: $F(1, 66) = 1.52$, $p = .22$). Training condition did not interact with differences in performance on the three grammatical conditions ($F(2, 130) = 1.13$, $p = .32$).

Native French speakers performed near ceiling on the grammaticality judgment task, across all three grammatical constructions (mean d' score = 3.7).

Paper-and-Pencil Questionnaire

Implicitly trained learners showed significantly poorer explicit knowledge of all three grammatical rules than explicitly trained learners, as measured by their ability to correct grammatical violations and provide verbal explanations for the rules under investigation (noun: $t(65) = 6.51$, $p < .001$; word order: $t(65) = 4.97$, $p < .001$; verb: $t(65) = 6.00$, $p < .001$).

Learners' performance on the grammaticality judgment task and on the paper-and-pencil questionnaire was highly correlated, with learners who more accurately discriminated grammatical violations of a given rule on the grammaticality judgment task showing a higher degree of explicit knowledge of the rule. These correlations held both within implicit (range r = .58–.89, $p < .001$) and explicit (range r = .75–.87, $p < .001$) groups as well as across all learners (range r = .76–.91, $p < .001$).

ERP Results

Group Analyses

As shown in Figure 3, native French speakers showed a biphasic response to two of the three types of syntactic violations, consisting of an early negativity followed by a later P600 effect (the early negativity was not significant in the noun agreement condition). In general, these earlier negativities were absent in the three groups of learners. Both implicit high-proficiency participants and explicit high-proficiency participants showed P600 effects to all three agreement conditions. In contrast, implicit low-proficiency participants did not elicit P600 effects in any agreement condition. Statistical tests confirmed these observations, as summarized in Table 3.

LAN time window. *Noun agreement (300–400 msec)*. No main effect of Group was found in this time window (Group × Condition: $F(3, 77) = 1.62$, $p = .191$, partial $\eta^2 = 0.059$; all distributional interactions: $p > .5$). Although a hint of a LAN can be seen in the native French speakers (Figure 3), follow-up analyses indicated that this effect did not reach significance (condition: $F(1, 20) = 0.01$, $p = .99$; all distributional interactions: $p > .3$). Similarly, no significant negativities were present in any of the three learner groups (all p values > .1).

Word order condition (300–450 msec). Significant differences in the negative effect at this time window were found between native French speakers and learners at posterior scalp sites (Group × Condition × Anterior/Posterior: $F(6, 146) = 2.87$, $p = .035$, partial $\eta^2 = 0.11$; analysis restricted to posterior regions: $t(73) = 2.51$, $p = .014$; 95% confidence interval (CI) = 0.32, 2.78; $\eta^2 = 0.079$). Follow-up analyses confirmed that native French speakers showed a significant negativity over posterior scalp regions (Condition × Anterior/Posterior: $F(2, 40) = 7.19$, $p = .011$; analysis restricted to posterior scalp sites, condition: $F(1, 20) = 6.80$, $p = .017$). In contrast, none of the learner groups showed significant negativities in this time window (all p values > .1).

Verb agreement (300–400 msec). Significant differences in the LAN were found between native French speakers

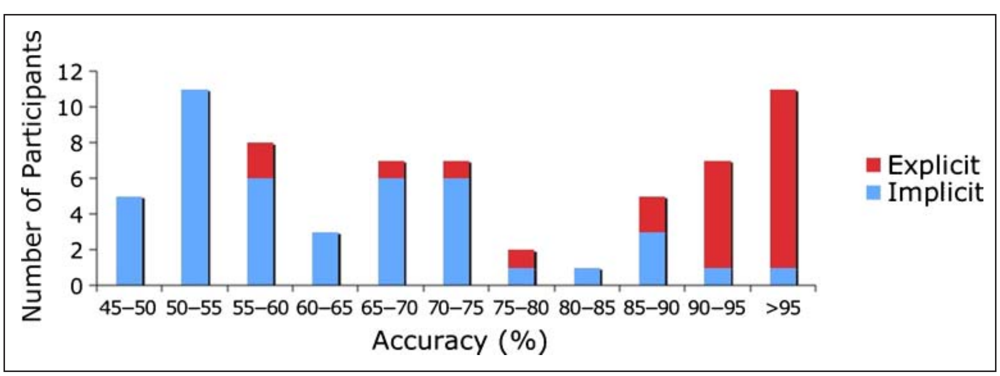
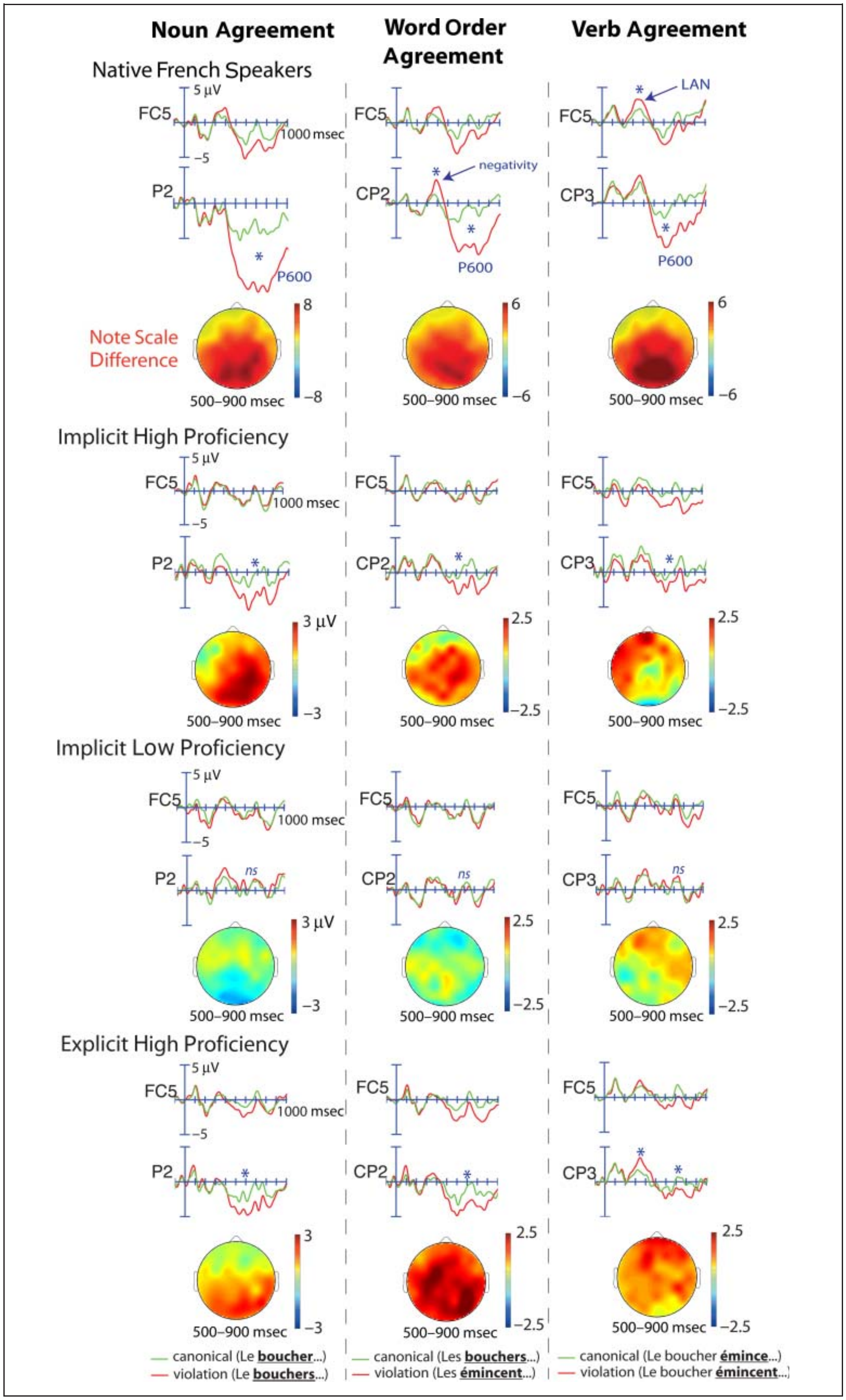


Figure 2. Behavioral performance of implicitly (blue) and explicitly (red) trained participants on the grammaticality judgment task. A clear behavioral advantage was found for explicitly trained participants.

Figure 3. Grand-averaged ERP waveforms time-locked to critical words constituting grammatical violations (displayed in red) and their canonical controls (displayed in green), for each of the four groups (shown on separate rows) and three agreement conditions (shown on separate columns), in the grammaticality judgment task. Violation effects are displayed at representative left anterior (FC5) and posterior electrodes (P2, CP2, and CP3). Voltage maps show the distribution of the violation effect between 500 and 900 msec for each group and agreement condition. Examples of the critical words for each condition are shown in bold at the bottom of the figure.



and learners at the left anterior scalp region (Group × Condition × Column × Anterior/Posterior: $F(12, 160) = 2.02$, $p = .032$, partial $\eta^2 = 0.085$; analysis restricted to left anterior region: Group × Condition: $t(65) = 2.23$, $p = .029$; CI = 0.14, 2.60; $\eta^2 = 0.071$). Follow-up analyses confirmed that native French speakers showed a significant LAN at the left anterior region (condition: $F(1, 20) = 5.37$, $p = .031$) as well as the left central region

Table 3. Summary of ERP Effects by Group and Agreement Condition

	Early Time Window			*P600 Time Window*		
	Noun	*Word Order*	*Verb*	*Noun*	*Word Order*	*Verb*
Native French						
Implicit high						
Explicit high						
Implicit low						

Blue indicates a significant negative effect, whereas red indicates a significant positive effect ($p < .05$). Lighter shades indicate a marginally significant effect ($p < .1$).

(condition: $F(1, 2) = 6.84$, $p = .017$). In contrast, the three learner groups did not show any evidence of a negativity at the left anterior region (all p values > .4). Unexpectedly, the explicit high-proficiency group showed a significant negativity over posterior sites (Condition × Anterior/Posterior: $F(2, 34) = 5.49$, $p = .029$; posterior ROIs, condition: $F(1, 17) = 4.96$, $p = .040$).

P600 time window (500–900 msec). Noun agreement. Significant differences in P600 amplitude were found between groups (Group × Condition: $F(3, 77) = 13.1$, $p < .001$, partial $\eta^2 = 0.34$). Planned contrasts indicated that native French speakers showed a significantly greater P600 effect than the three learner groups ($t(77) = 5.82$, $p < .001$; CI = 2.10, 4.29; $\eta^2 = 0.31$) and that the implicit and explicit high-proficiency groups elicited a significantly larger P600 than the implicit low-proficiency group ($t(77) = 2.09$, $p = .040$; CI = 0.06, 2.39; $\eta^2 = 0.054$). In contrast, there were no significant differences in P600 amplitude between the implicit high-proficiency and explicit high-proficiency groups ($t(77) = 0.76$, $p = .45$; CI = −0.85, 1.92; $\eta^2 = 0.0074$).

Follow-up analyses revealed that native French speakers (condition: $F(1, 20) = 72.1$, $p < .001$), the implicit high-proficiency group (condition: $F(1, 17) = 7.96$, $p = .012$), and the explicit high-proficiency group (Condition × Anterior/Posterior: $F(1, 40) = 6.14$, $p = .018$; follow-up analysis: $F(1, 20) = 6.06$, $p = .023$) all elicited significant P600 effects. In contrast, the implicit low-proficiency group did not show a significant P600 effect ($n = 21$; condition: $F(1, 20) = 2.38$, $p = .138$; all distributional interactions: $p > .1$).

Distributional group comparisons carried out on normalized data indicated that there were significant distributional differences among groups (Group × Column: $F(4, 114) = 3.96$, $p = .005$; Group × Anterior/Posterior: $F(4, 114) = 3.77$, $p = .022$). Contrasts revealed that the P600 effect elicited by native French speakers showed a significantly more medial and posterior distribution than the P600 effect observed in high-proficiency learners (Group × Column: $F(2, 116) = 4.39$, $p = .016$; Group × Anterior/Posterior: $F(4, 114) = 7.65$, $p = .005$). In addition, implicit high-proficiency learners showed a more right-lateralized effect than explicit high-proficiency learners (Group × Column: $F(2, 74) = 4.18$, $p = .019$).

Word order agreement. Significant P600 amplitude differences were found between groups (Group × Condition: $F(3, 73) = 5.57$, $p = .002$, partial $\eta^2 = 0.19$). Native French speakers elicited a significantly larger P600 effect than the three learner groups ($t(73) = 3.28$, $p = .002$; CI = 0.77, 3.17; $\eta^2 = 0.13$), and implicit and explicit high-proficiency groups elicited a significantly larger P600 than the implicit low-proficiency group ($t(73) = 2.21$, $p = .030$; CI = 0.15, 2.78; $\eta^2 = 0.063$). Similar to the noun agreement condition, no significant differences in P600 amplitude were found between implicit high-proficiency learners and explicit high-proficiency learners ($t(73) = 0.97$, $p = .33$; CI = −2.29, 0.79; $\eta^2 = 0.013$).

Native French speakers (condition: $F(1, 20) = 18.62$, $p < .001$) and explicit high-proficiency learners showed significant P600 effects (condition: $F(1, 18) = 23.9$, $p < .001$), whereas the P600 effect observed in implicit high-proficiency nearly reached significance (condition: $F(1, 17) = 3.85$, $p = .066$; fully significant over four most right-posterior regions: $F(1, 17) = 5.15$, $p = .036$). Implicit low-proficiency participants did not show a significant P600 effect (condition: $F(1, 18) = 0.008$, $p = .93$; all distributional interactions: $p > .1$).

No significant distributional differences between native French speakers, implicit high-proficiency learners, and explicit high-proficiency learners were found (p values > .5).

Verb agreement. Significant P600 amplitude differences were found between groups (Group × Condition: $F(3, 65) = 5.1$, $p = .003$, partial $\eta^2 = 0.19$). Native French speakers showed a significantly larger P600 effect than the three learner groups ($t(65) = 3.77$, $p < .001$; CI = 1.40, 3.40; $\eta^2 = 0.18$). In contrast to the noun and word order agreement conditions, the P600 elicited by the implicit and explicit high-proficiency groups was not significantly different from that elicited by the implicit low-proficiency group ($t(65) = 0.72$, $p = .48$; CI = −1.91, 0.86; $\eta^2 = 0.0079$). Again, the P600 effect observed in implicit high-proficiency learners and explicit high-proficiency learners did not significantly differ in amplitude ($t(65) = 0.13$, $p = .90$; CI = −1.82, 1.60; $\eta^2 < 0.001$).

Follow-up analyses indicated that significant positivities were present in native French speakers (condition: $F(1, 20) = 18.62$, $p < .001$), implicitly trained high-proficiency learners (condition: $F(1, 10) = 7.336$, $p = .022$), and explicitly trained high-proficiency learners (condition: $F(1, 18) = 23.9$, $p < .001$). No significant effect was observed in implicitly trained low-proficiency learners (condition: $F(1, 18) = 0.80$, $p = .383$).

Group differences in the distribution of this effect were observed (Group × Column: $F(4, 94) = 4.02$, $p = .006$; Group × Anterior/Posterior: $F(4, 94) = 7.42$, $p = .001$): The effect elicited by native French speakers was significantly more medial and posterior in distribution than the effect observed in high-proficiency learners (Group × Column: $F(2, 96) = 5.32$, $p = .007$; Group × Anterior/Posterior: $F(2, 96) = 15.0$, $p < .001$). No distributional differences were found between implicit and explicit high-proficiency groups (p values > .1).

Subsampling analysis. A potential concern is that the lack of P600 effects in the implicit low-proficiency groups may be because of the smaller number of correct trials included in each individual participant average. To address this issue, we performed a subsampling analysis for each agreement condition, in which a random subsample of trials was removed from the data set of each implicit high-proficiency subject to equate the average number of trials per individual average in both high- and low-proficiency groups. As in our original analysis, implicit high-proficiency participants showed significant P600 effects in all three agreement conditions (all p values < .05). This analysis confirms that the lack of a P600 effect in the low-proficiency groups cannot be because of differences in trial numbers between high- and low-proficiency groups, indicating that ERP differences between groups reflect true differences in neural processing.

Proficiency–P600 Correlational Analyses

Proficiency (d') on the grammaticality judgment task predicted P600 amplitude across learners in both the noun violation (Figure 4A) and word order violation (Figure 4B) conditions. In the noun violation condition ($n = 60$), proficiency correlated with P600 amplitude at the midline posterior ($r = .38$, $p = .003$), right posterior ($r = .34$, $p = .009$), left posterior ($r = .28$, $p = .028$), and right central ($r = .29$, $p = .025$) regions. In the word order violation condition ($n = 58$), significant correlations between proficiency and P600 amplitude were found at the right posterior ($r = .318$, $p = .015$), left posterior ($r = .291$, $p = .027$), midline central ($r = .307$, $p = .019$), left central ($r = .299$, $p = .023$), and midline anterior ($r = .319$, $p = .015$) regions. Although correlations were in the same direction, proficiency was not a significant predictor of P600 amplitude in the verb violation condition ($n = 49$, all p values > .1; Figure 4C).

Training condition (implicit vs. explicit) did not predict P600 amplitude in the noun violation or the verb violation condition at any ROI (all p values > .1). However, in the word order violation condition, training significantly

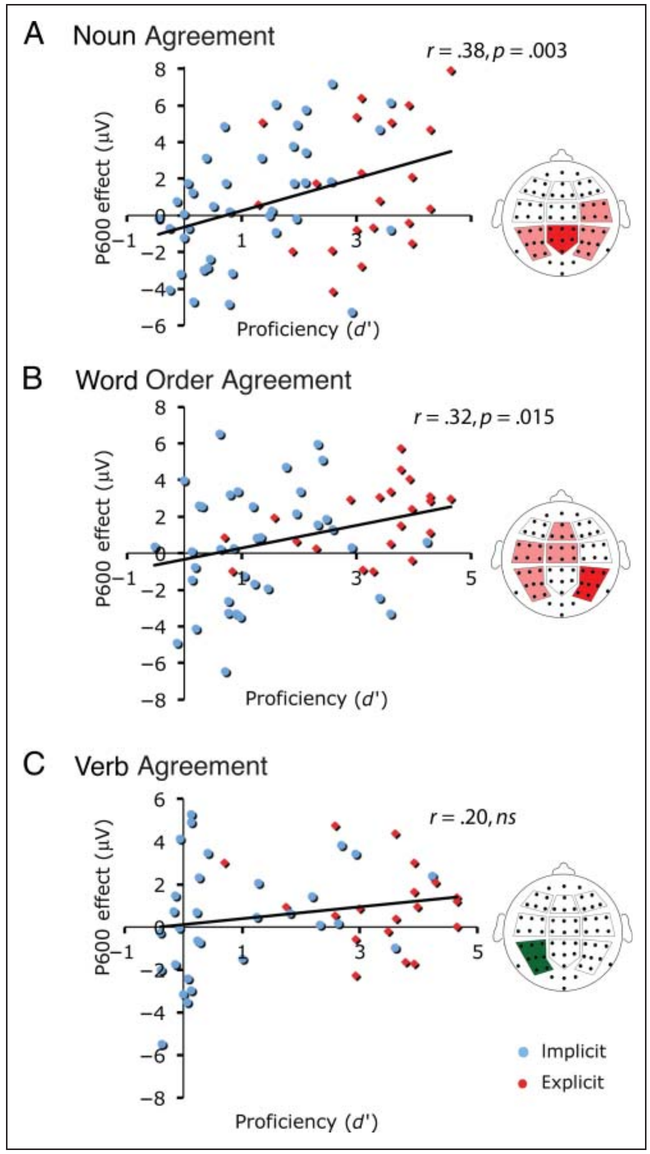


Figure 4. Scatterplots showing correlations between proficiency (d') and P600 amplitude across implicit (blue) and explicit (red) learners, at representative channel groups, for each agreement condition in the grammaticality judgment task. (A) Proficiency–P600 correlation in the noun agreement condition, at the midline posterior region (shown in dark red on the electrode montage map). Other regions that also showed significant proficiency–P600 correlations are indicated in light red on the montage. (B) Proficiency–P600 correlation in the word order agreement condition, at the right posterior region (shown in dark red). Other regions that also showed significant proficiency–P600 correlations are indicated in light red on the montage. (C) Proficiency–P600 correlation in the verb agreement condition, at the left posterior region (shown in green on the electrode montage map to indicate lack of significance). No significant correlations were found at any channel group in this condition.

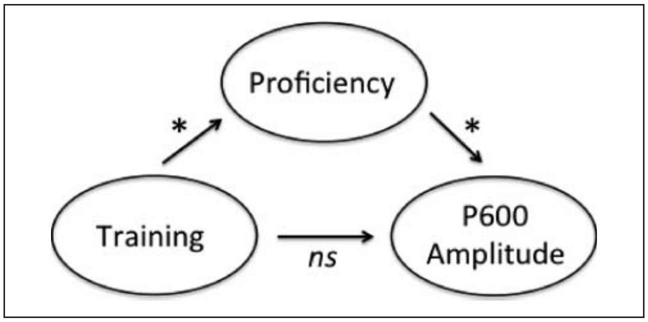


Figure 5. Conceptual summary of mediation analyses designed to examine the connections between training, proficiency and P600 amplitude. Training condition (implicit vs. explicit) predicts proficiency, which in turn predicts P600 amplitude. However, training does not directly predict P600 amplitude.

predicted P600 amplitude at a single electrode group—the right anterior ROI ($r = .28, p = .036$).

Mediation analyses designed to examine the relationship between training condition, proficiency, and P600 amplitude indicated that training did not have a direct effect on P600 amplitude at any ROI when proficiency was entered as a mediator in the model (p values at all ROIs $> .05$). In the noun condition, training was found to have an indirect effect on P600 amplitude at the midline posterior ($t(57) = 2.51, p = .015$), right central ($t(57) = 2.57, p = .013$), and right posterior ($t(57) = 2.0, p = .05$) region. These results indicate that training condition predicts proficiency, which in turn predicts P600 amplitude, but that training per se is not related to P600 amplitude (Figure 5).

DISCUSSION

As expected based on previous literature, native French speakers showed a biphasic ERP response to two of the three violation types, consisting of an early negativity followed by a later P600 effect (the early negativity in the noun agreement condition was not statistically significant).[1] In comparison, ERP violation effects at the early time window were generally absent in the English-speaking learners. However, learning modulated ERP effects in the later P600 time window. Critically, both implicitly and explicitly trained participants who successfully learned a given grammatical rule elicited significant P600 effects. In contrast, implicitly trained participants who did not successfully acquire the novel grammatical rules did not produce P600 effects to violations. The magnitude of the P600 effect was correlated with behavioral proficiency in the noun and word order agreement conditions.

Behaviorally, training condition significantly predicted proficiency, with a clear behavioral advantage for explicit over implicit training revealed. However, explicit training did not produce stronger neural effects; proficiency, rather than training, directly predicted P600 amplitude when both proficiency and training were accounted for (Figure 5).

Effects of Implicit L2 Training

The major novel finding revealed by our study is that brief implicit exposure alone is capable of producing a P600 effect in L2 learners: After a mere hour of implicit exposure to L2 grammar, learners who achieved adequate knowledge of noun, word order, and verb agreement rules showed significant positivities to violations of these rules. Although there are quantitative differences between the P600 effects elicited by these successful implicit learners and native French speakers, the effects are qualitatively similar in terms of distribution and time course, at least in the noun and word order agreement conditions (Figure 3). These similarities suggest that these implicitly trained learners recruited some of the same neural mechanisms as those employed by native speakers for syntactic processing, even during this very early stage of learning.

Although a number of previous studies have demonstrated that the P600 can emerge after relatively brief periods of more explicit types of training (Morgan-Short, Steinhauer, et al., 2012; McLaughlin et al., 2010; Davidson & Indefrey, 2008; Mueller et al., 2005, 2007, 2008; Osterhout et al., 2008; Friederici et al., 2002), the finding that the P600 is also sensitive to learning produced by implicit exposure demonstrates that these mechanisms can be recruited under a variety of different exposure conditions (for a similar finding, see Morgan-Short, Steinhauer, et al., 2012). The remarkable plasticity of the P600 converges with domain-general evidence, which suggests that controlled, attention-dependent processes are highly malleable, remaining sensitive to environmental input throughout life. For example, late blind individuals show an enhanced P300 to auditory stimuli presented in the periphery relative to sighted controls but, in contrast to congenitally blind individuals, show no changes in the N1 response (Fieger, Roder, Salejarvi-Teder, Hillyard, & Neville, 2006). Late, controlled processing may thus represent a powerful lifelong learning mechanism, allowing adults to compensate for delays in acquisition by engaging in slower, more effortful processes (Schneider & Shiffrin, 1977; Shiffrin & Schneider, 1977).

Our finding that attention strongly predicted learners' success in acquiring the novel L2 grammar provides further support for this idea. Although all implicitly trained participants were given the same instructions during the initial exposure phase, some participants naturally attended to the grammatical regularities of the stimuli, whereas others did not. Importantly, learners who reported attending at least partially to the grammatical structure of the sentences significantly outperformed their counterparts who attended only to the vocabulary. This result converges with previous behavioral evidence showing that attention and awareness play a key role in acquiring novel L2 syntactic rules (Leow & Bowles, 2005; Leow, 1998).

Although successful learners in the implicit group were trained on the novel L2 grammar implicitly, that is, without being instructed to attend to or explicitly decipher the L2 grammatical rules, they nonetheless gained explicit, verbalizable knowledge of the underlying grammar. As demonstrated by the high correlations between performance on the grammaticality judgment task and on the paper-and-pencil questionnaire, learners who performed well on the grammaticality judgment task were able to pinpoint the source of the grammatical errors in grammatically incorrect exemplars and to explicitly describe the underlying grammatical rules. In contrast, participants who performed poorly on the task did not show any explicit knowledge of the grammatical rules under investigation. Thus, although performance on the grammaticality judgment task can potentially reflect either implicit linguistic competence or explicit metalinguistic knowledge (Paradis, 2004), the learners in our study appeared to depend primarily on explicit knowledge to support their decisions. This finding suggests that explicit knowledge is key in the acquisition of a late-learned L2 grammar system, at least during early learning stages, even under implicit learning conditions.

By disentangling age of acquisition and type of learning, this study provides evidence supporting the idea that L2 syntactic processing depends on explicit or declarative mechanisms, as put forward by recent neurobiological models of language processing (Ullman, 2001a, 2001b, 2005; Paradis, 1997, 2004). Paradis' model proposes that, in contrast to L1 syntactic acquisition, which is mediated by implicit mechanisms, the acquisition and processing of a late-learned L2 syntax is mediated by explicit mechanisms that depend on conscious awareness, at least during early learning stages. Similarly, Ullman's model claims that L1 syntactic processing relies on procedural memory, whereas L2 syntax depends initially on declarative memory. However, most of the direct evidence supporting these claims comes from comparisons of native speakers and late bilinguals in which age of acquisition and learning condition are confounded: Whereas young children typically acquire their L1 grammar largely implicitly, adults learning a foreign language are likely to receive at least some explicit instruction in their L2. By examining the effects of implicit language exposure independently of age of acquisition, this study provides further evidence that late-learned L2 grammar is primarily mediated by explicit mechanisms, even under implicit exposure conditions. Future research could test young children on a similar learning-based experimental task to examine whether children recruit implicit rather than explicit mechanisms to process a novel L2 grammar.

Comparison of Implicit versus Explicit Training

Although implicit training is capable of rapidly producing P600 effects similar to those observed after explicit training, our results nonetheless indicate a clear behavioral advantage for explicit instruction, with explicitly trained learners achieving an average accuracy of 89% compared with the 64% accuracy achieved by implicitly trained learners (Figure 2). This result is hardly surprising; explicitly trained participants needed only to apply the formal rules they had been taught to achieve perfect performance, whereas implicitly trained participants did not have easy access to these rules, having received no instruction to attend to the underlying grammatical regularities of the stimuli during the exposure period. These findings converge with previous behavioral results in the L2 acquisition literature, which generally find that explicitly trained learners outperform their implicitly trained counterparts (e.g., Spada & Tomita, 2010; Norris & Ortega, 2000, 2001; Rosa & O'Neill, 1999; DeKeyser, 1995).

Although explicit instruction increases the chance of successful acquisition, it does not appear to alter the neural mechanisms involved in learning. Although null results must be interpreted with caution, P600 effects in implicit and explicit high-proficiency groups were qualitatively as well as quantitatively similar, as indicated by both significance testing and effect size measures. These similarities held for amplitude as well as distribution, with only a single distributional difference emerging across the three agreement conditions (Figure 3). Furthermore, mediation analyses indicated that proficiency, not training, directly predicted P600 amplitude in the noun and word order agreement conditions (Figures 4 and 5). Thus, both our implicitly and explicitly trained high-proficiency participants appear to have relied on similar neural mechanisms, indexed by the P600, when processing the novel L2 grammar.

This finding differs from results reported by Morgan-Short, Steinhauer, et al. (2012), who found ERP differences to syntactic violations as a function of training type using an artificial language paradigm. Explicitly trained learners showed an anterior positivity between 350- and 700-msec poststimulus and a P600 effect, whereas implicitly trained learners showed a P600 and an extended anterior negativity between 150- and 900-msec poststimulus. The authors interpreted this as evidence that implicit training is capable of recruiting native-like neural mechanisms, whereas explicit training is not. Methodological differences between Morgan-Short et al.'s study and the present one, such as the use of an artificial language, the use of feedback during training, and the use of a more extensive training procedure spanning multiple days, may represent one possible explanation for these inconsistent results, although future studies will be needed to clarify this issue.

As discussed previously, successful acquisition of a novel late-learned L2 grammar in our paradigm appeared to crucially depend on access to explicit, verbalizable representations of L2 grammar rules. The finding that implicitly and explicitly trained learners show similar P600 effects to violations suggests that both groups of learners rely on explicit grammar knowledge to an equal extent when making grammaticality judgments. These results indicate that explicit representations of L2 grammar rules may be acquired through multiple learning pathways: These rules can be directly taught via explicit formal instruction or may be indirectly deduced through passive, implicit exposure, albeit often with more difficulty. Once acquired, these explicit L2 grammar representations appear to facilitate the conscious detection and processing of grammatical violations, producing qualitatively similar P600 effects in both implicitly and explicitly trained learners. The suggestion that explicit knowledge of an underlying rule may be necessary to elicit a P600 effect in beginning learners converges with findings from SRT studies, in which N200 and P300 effects to deviant stimuli are observed only in learners who have some degree of explicit knowledge about the underlying sequence (Rüsseler, Hennighausen, Munte, & Rösler, 2003; Rüsseler & Rösler, 2000; Eimer, Goschke, Schlaghecker, & Stürmer, 1996).

Consistent with previous reports (McLaughlin et al., 2010; Pakulak & Neville, 2010), performance on the grammaticality judgment task significantly correlated with P600 amplitude in the noun and word order violation conditions, indicating that learners with stronger behavioral sensitivity to grammatical violations showed more robust P600 effects (Figure 4). These results suggest that proficiency plays a crucial role in the emergence of the P600 or, conversely, that speakers who engage to a greater extent in the processes indexed by the P600 achieve better behavioral performance on grammatical processing tasks. In this study, participants who acquired a clearer, more complete understanding of a given L2 grammatical rule were likely better able to detect and process grammatical violations, leading to better performance on the grammaticality judgment task and a more robust P600 effect.

Conclusions

Our results suggest that a late-learned L2 is processed through similar neural mechanisms, regardless of whether it was acquired through implicit exposure or explicit instruction. Although explicit training increases the chance of successfully acquiring a novel grammar, at least in the short term, it does not appear to alter the neural mechanisms that mediate L2 processing. Similar to explicitly trained L2 learners, successful implicitly trained learners (1) recruited controlled, attention-dependent mechanisms to detect and process syntactic violations, as indexed by the P600, and (2) gained explicit knowledge about the L2 grammatical rules. In summary, late controlled mechanisms indexed by the P600 appear to play a crucial role in L2 grammar processing, regardless of how the L2 is acquired. This finding underscores the remarkable plasticity of late, attention-dependent processes and their importance in lifelong learning. Results from this study may also be of interest from an applied perspective, providing educators with evidence that different types of training produce similar neural outcomes in L2 learners.

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Note

1. In the word order condition, a posterior, rather than an anterior, negativity was observed. Although somewhat unexpected, posterior negativities or N400 components have occasionally been reported to word category violations (Gunter & Friederici, 1999) as well as to violations of morphology (Friederici et al., 1993) and thematic role assignment (Frisch & Schlesewsky, 2001, 2005; Friederici & Frisch, 2000). Gunter and Friederici (1999) interpreted the finding of an N400 to word category violations as reflecting the violation of semantic expectation for an agent. Similarly, in this study, the initial sentence context may have established semantic expectations for a particular lexical category (noun or verb). The violation of this expectancy may have triggered semantic processing mechanisms, eliciting a more posterior negativity or N400 effect.

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