Explicit and Implicit Second Language Training Differentially Affect the Achievement of Native-like Brain Activation Patterns

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Abstract

■ It is widely believed that adults cannot learn a foreign language in the same way that children learn a first language. However, recent evidence suggests that adult learners of a foreign language can come to rely on native-like language brain mechanisms. Here, we show that the type of language training crucially impacts this outcome. We used an artificial language paradigm to examine longitudinally whether explicit training (that approximates traditional grammar-focused classroom settings) and implicit training (that approximates immersion settings) differentially affect neural (electrophysiological) and behavioral (performance) measures of syntactic processing. Results showed that performance of explicitly and implicitly trained groups did not differ at either low or high proficiency. In contrast, electrophysiological (ERP) measures revealed striking differences between the groups' neural activity at both proficiency levels in response to syntactic violations. Implicit training yielded an N400 at low proficiency, whereas at high proficiency, it elicited a pattern typical of native speakers: an anterior negativity followed by a P600 accompanied by a late anterior negativity. Explicit training, by contrast, yielded no significant effects at low proficiency and only an anterior positivity followed by a P600 at high proficiency. Although the P600 is reminiscent of native-like processing, this response pattern as a whole is not. Thus, only implicit training led to an electrophysiological signature typical of native speakers. Overall, the results suggest that adult foreign language learners can come to rely on native-like language brain mechanisms, but that the conditions under which the language is learned may be crucial in attaining this goal. ■

INTRODUCTION

Learning a language as a child is typically natural and effortless. Learning a language as an adult, in contrast, is often fraught with difficultly. Indeed, it is widely believed that adults are not able to learn a second language (L2) using the same neurocognitive mechanisms that children rely on for their first language (L1; Bley-Vroman, 1990; Lenneberg, 1967). However, recent evidence shows that even for aspects of language, such as grammar, that are difficult to learn in L2 (Weber-Fox & Neville, 1996; Newport, 1993), L1-like brain processing may eventually be attained (Gillon Dowens, Vergara, Barber, & Carreiras, 2009; Steinhauer, White, & Drury, 2009; Hahne, Mueller, & Clahsen, 2006; see below for more details). Yet, a critical gap in our understanding of adult-learned L2 remains: It is not yet known whether L1-like brain processing can always be attained or whether certain factors, such as the input conditions under which an L2 is learned, crucially constrain it. Here, we test for the first time whether more explicit input conditions (as in traditional grammar-focused classroom settings) or more implicit input conditions (as are found in immersion settings) differentially affect the attainment of native language brain mechanisms for L2 syntactic processing.

Although neural outcomes of explicit versus implicit L2 training conditions have never been examined, a large body of behavioral research has addressed this issue (see Norris & Ortega, 2000). Despite the popular belief that learning a foreign language as an adult is easier when one is immersed in the language and imbibes it largely implicitly, behavioral advantages have usually been reported for explicit rather than implicit training—wherein explicit training is defined as training that provides learners with information about L2 grammar rules or directs them to search for rules, and implicit training is defined as training that engages L2 learners with the target language but does not provide any explicit information or direction to search for rules (Norris & Ortega, 2000). Although in some studies, implicit and explicit training lead to similar levels of L2 learning (Sanz & Morgan-Short, 2005; VanPatten & Oikkenon, 1996), we are not aware of any clear empirical evidence suggesting an advantage for implicit training.

Limitations of this body of behavioral research, however, have made it difficult to arrive at clear conclusions regarding explicit versus implicit training. Studies typically examine learning effects of explicit and implicit training on an L2 that was already learned to low levels of proficiency

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(generally in classroom settings). The amount of training provided is usually quite small (around 1 hr), so participants remain at lower proficiency levels even after training (Rosa & Leow, 2004; Sanz & Morgan-Short, 2004; VanPatten & Oikkenon, 1996). Thus, any advantages of explicit or implicit training on attaining high proficiency are, surprisingly, still unknown. Additionally, because learning under implicit conditions is thought to take longer than under explicit conditions (Ellis, 2005), such short durations may bias the results toward an advantage for explicit training (Ellis et al., 2009; Norris & Ortega, 2000). Moreover, explicit training conditions often provide more input than implicit training conditions, in that they provide explicit information in addition to the stimuli provided in the implicit training condition (Rosa & Leow, 2004; VanPatten & Oikkenon, 1996). Thus, neither time-on-task nor the total amount of input (of different types) is systematically controlled. Finally, the assessment of L2 in training studies has generally focused on explicit knowledge (available to conscious awareness; Norris & Ortega, 2000), providing another bias for explicit training (Ellis et al., 2009; Sanz & Morgan-Short, 2005; Norris & Ortega, 2000). Thus the reported advantages for explicit training remain very much in question (Ellis et al., 2009; Sanz & Morgan-Short, 2005).

We took a different approach to examine this issue. First, rather than training participants on a natural language to which they had already been exposed, we trained them on an artificial language, Brocanto2. Participants were trained across multiple sessions to actually speak and understand this language, which refers to pieces and moves of a chess-like computer game. The grammar of the language fully complies with grammars of natural languages. However, the number of rules and vocabulary items is very small. Thus, the language is learnable to high proficiency in the order of hours, facilitating longitudinal examination of training effects from low to high proficiency. Moreover and unlike natural languages, an artificial language allows a range of factors to be easily controlled, such as the amount, timing, and type of exposure (before as well as during training), and the (dis)similarity of the language (e.g., phonology and syntax) to the speaker's native language (L1). Importantly, Brocanto2 is a variant of a previously developed artificial language (Brocanto), which, when learned to high proficiency, shows L1-like brain patterns (Opitz & Friederici, 2003; Friederici, Steinhauer, & Pfeifer, 2002). Artificial languages such as these may thus constitute "test tube" models of natural language that allow one to examine issues that would be difficult, if not impossible, to address in natural language (Hancock & Bever, 2009; Friederici et al., 2002).

Second, whereas previous L2 research of explicit and implicit training has been purely behavioral, here we test neural measures, although we also examine behavioral (performance) measures. Crucially, although performance measures can reveal how well an L2 is learned, they cannot easily tell us how it is learned or processed, that is, what neurocognitive mechanisms underlie it (Ullman, 2005). In fact, a particular limitation of performance data is that similar performance between two conditions or groups does not necessarily implicate reliance on similar neural mechanisms. In other cognitive domains, it has been shown that, although different task demands promote the use of different brain systems (declarative and procedural memory), the material may be learned about equally well by both (Foerde, Knowlton, & Poldrack, 2006; Poldrack et al., 2001). Similarly, high L2 performance does not necessarily suggest a dependence on native language neurocognitive mechanisms (Ullman, 2005). Yet the reliance on L1 mechanisms may be an important goal of L2 learning, because these mechanisms are evidently extremely well suited to language. Indeed, it is quite plausible that native-like proficiency might be reliably attained only with native language neurocognitive mechanisms. Thus, elucidating the neural as well as performance outcomes of L2 training seems essential.

ERPs may be the best method for this purpose. ERPs reflect real-time scalp-recorded electrophysiological brain activity of cognitive processes that are time-locked to the presentation of target stimuli. Unlike other neuroimaging techniques (fMRI and magnetoencephalography), ERP research has revealed a set of widely studied language-related activation patterns ("ERP components") in L1, whose characteristics and underlying functions are relatively well understood (see below). These components thus provide a clear frame of reference for examining the attainment of native language processing in L2, including in studies of artificial language (Friederici et al., 2002). Unlike hemodynamic imaging methods like fMRI, ERPs provide excellent temporal resolution, allowing one to examine the time course of processing. Examining ERP along with behavioral measures improves the likelihood of detecting effects, in particular because ERPs can be sensitive to effects that are not found with behavioral measures, including in language learning studies (Tokowicz & MacWhinney, 2005; McLaughlin, Osterhout, & Kim, 2004). Finally, unlike the performance measures in many previous L2 training studies, which are designed to reveal explicit knowledge, without any direct measure of the contribution of implicit knowledge, ERPs have the potential to reveal processes underlying both types of knowledge.

In L1, different types of processing difficulties elicit different ERP components (Steinhauer & Connolly, 2008). Difficulties in lexical/semantic processing in L1 (e.g., "John has his coffee with milk and *concrete"—the * indicates a violation word) elicit central/posterior bilaterally distributed negativities (N400s) that often peak about 400 msec poststimulus onset for written words (Kutas & Hillyard, 1980), and tend to be relatively long lasting in spoken language (Steinhauer, Alter, & Friederici, 1999; Holcomb & Neville, 1991). N400s reflect aspects of lexical/semantic processing and may depend on the declarative memory brain system (Lau, Phillips, & Poeppel, 2008; Steinhauer & Connolly, 2008; Ullman, 2001).

Disruptions of rule-governed (morpho)syntactic processing in L1, including word order ("phrase structure") violations (e.g., "The man hoped to *meal the enjoy with friends") often produce three components. First, such disruptions can, but do not always (Hagoort & Brown, 1999), elicit early (150–500 msec) left-to-bilateral anterior negativities (ANs; Steinhauer & Connolly, 2008; Kaan, 2007; Friederici, Pfeifer, & Hahne, 1993; Neville, Nicol, Barss, Forster, & Garrett, 1991). Less left-lateralized (more bilateral) ANs may be associated with lower L1 proficiency (Pakulak & Neville, 2010). Because these negativities are not restricted to the left hemisphere, the term "AN" may be more appropriate than the traditional term "LAN" and will be adopted here. Although (morpho)syntactic violations do not always elicit ANs (Hagoort & Brown, 1999), this component is generally found in response to auditorily presented word order violations (Steinhauer & Drury, in press), which are examined here. ANs appear to reflect aspects of rule-governed automatic structure building (Steinhauer & Drury, in press; Hasting & Kotz, 2008; van den Brink & Hagoort, 2004; Friederici & Kotz, 2003; Hahne & Friederici, 1999) and have been posited to depend on the procedural memory brain system, which seems to underlie aspects of grammar (Ullman, 2001, 2004). Second, (morpho)syntactic disruptions usually elicit late (600 msec) centro-parietal positivities (P600s; Kaan, Harris, Gibson, & Holcomb, 2000; Osterhout & Holcomb, 1992), which are linked to controlled (conscious) processing and structural reanalysis (Kaan et al., 2000; Hahne & Friederici, 1999). The biphasic pattern of an AN followed by a P600 may be characteristic of native speaker processing of (morpho)syntactic violations (Steinhauer & Drury, in press; Hasting & Kotz, 2008; Steinhauer & Connolly, 2008; van den Brink & Hagoort, 2004; Friederici et al., 1993). Finally, such violations can also elicit later (600–2000 msec) sustained ANs ("late ANs"), which often show bilateral distributions (Gillon Dowens et al., 2009; Martin-Loeches, Munoz, Casado, Melcon, & Fernandez-Frias, 2005; Friederici et al., 1993). Although these late negativities tended not to be discussed in earlier studies (Hahne & Friederici, 1999; Friederici et al., 1993), more recent research has commonly reported them, especially for auditorily presented word order violations (Steinhauer & Drury, in press; Kotz, 2009; Steinhauer & Connolly, 2008; Kaan, 2007). Late ANs may reflect increased working memory demands (Martin-Loeches et al., 2005). It has also been proposed that the prototypical ERP response to phrase structure violations consists one sustained AN (e.g., from about 200 msec to later than 1000 msec) together with a P600, which can temporarily diminish or eliminate this AN (Steinhauer & Drury, in press). In summary, the AN, P600, and late AN are all commonly elicited in L1 in response to (morpho)syntactic violations, in particular for auditorily presented word order violations (Kotz, 2009; Steinhauer & Connolly, 2008; Kaan, 2007).

ERP studies of L2 processing have revealed the following. The neurocognition of lexical/semantic processing does not differ qualitatively between L1 and L2, reliably eliciting N400s in both cases, even after minimal L2 exposure, although in some cases the N400 in L2 is delayed or longer lasting (Steinhauer et al., 2009; McLaughlin et al., 2004; Ullman, 2001). In contrast, L2 differs from L1 in aspects of (morpho)syntactic (grammatical) processing, in particular at lower levels of exposure and proficiency (Steinhauer et al., 2009; Ullman, 2001). (Note that proficiency and exposure are generally correlated and are difficult to tease apart in studies of L2; for simplicity, hereafter we usually refer only to proficiency levels rather than to both proficiency and exposure.) At lower levels, ANs are typically absent, with participants instead showing no negativity at all (Ojima, Nakata, & Kakigi, 2005; Hahne & Friederici, 2001) or eliciting N400s or N400-like posterior negativities (Osterhout et al., 2008; Weber-Fox & Neville, 1996). However, recent studies have reported ANs in higher proficiency L2 (Gillon Dowens et al., 2009; Steinhauer et al., 2009; Isel, 2007; Hahne et al., 2006; Ojima et al., 2005; but see Chen, Shu, Liu, Zhao, & Li, 2007). These ANs are sometimes bilaterally distributed (Isel, 2007), possibly because of lower L2 proficiency (Steinhauer et al., 2009). P600s are generally found in L2, particularly at higher proficiency (Gillon Dowens et al., 2009; Steinhauer et al., 2009; Osterhout et al., 2008; Hahne et al., 2006; Weber-Fox & Neville, 1996). In some studies of high proficiency L2, the AN and P600 are both elicited in response to (morpho)syntactic violations (Gillon Dowens et al., 2009; Steinhauer et al., 2009; Hahne et al., 2006). This L1-like biphasic response has also been found in highly proficient learners of an artificial language (Friederici et al., 2002). Finally, late ANs have also been observed in L2, again mainly (but not always) at higher proficiency (Chen et al., 2007; Isel, 2007; but see Ojima et al., 2005), in some cases together with an AN–P600 biphasic response (Gillon Dowens et al., 2009).

Overall, ERP studies of L2 suggest that, although the neurocognition of lexical/semantic processing is similar in L1 and L2, the neural processes underlying L2 (morpho)syntax depend on the learner's level of proficiency (or exposure). At lower levels, L1 brain processes (as indexed by ANs and P600s, as well as late ANs) are uncommon or absent. Instead of the automatic structure building relied on in L1 (indexed by ANs), (morpho)syntax in lower proficiency L2 may, at least in some circumstances, depend on lexical/semantic processes, as reflected by the N400. In contrast, at higher proficiency levels, the presence of ANs and P600s, in particular in biphasic responses, as well as late ANs, suggest that L1 brain processing can in fact be achieved in L2, although the type and amount of exposure and the level of resulting proficiency necessary to achieve native-like brain mechanisms remain unknown.

The study reported here moves beyond the examination of proficiency in L2. It tests whether the conditions under which an L2 is learned, in particular explicit versus implicit training conditions (holding the amount of training time constant), have distinct effects on neural (ERP) and behavioral (performance) measures of syntactic processing.

Adult participants learned to understand and speak the artificial language Brocanto2 in either explicit or implicit training conditions. ERPs were acquired while participants judged the acceptability of correct and incorrect (word order violation) Brocanto2 sentences, first at low exposure and proficiency and then at high.

METHODS

Participants

We tested 41 right-handed, healthy adults who were not fluent in any language other than English, based on self-report. Because the artificial language was structurally similar to Romance languages, exposure to any Romance language was restricted to not more than 3 years of classroom exposure and 2 weeks of immersion in a Romance language environment. Participants were randomly assigned to the explicit or implicit training groups within each gender and were included in the analysis if they reached a low level of proficiency (see below), completed all tasks, and did not exhibit a large number of artifacts in their ERP data. Data from 30 participants (explicit: $n = 16$, 7 women; implicit: $n = 14$, 7 women) were analyzed. The explicit and implicit groups did not differ (unpaired t tests, $ps > .139$) on age (explicit: $M = 24.25$ years, $SD = 4.34$ years; implicit: $M = 24.71$ years, $SD = 5.57$ years), years of education ($M = 16.25$ years, $SD = 2.82$ years; $M = 16.43$ years, $SD = 2.17$ years), age of first exposure to any second language ($M = 12.63$ years, $SD = 4.72$ years; $M = 12.64$ years, $SD = 4.06$ years), or years of exposure to either Romance languages ($M = 1.51$ years, $SD = 1.35$ years; $M = 1.95$ years, $SD = 1.30$ years) or to any other nonnative language ($M = 3.45$ years, $SD = 1.71$ years; $M = 4.94$ years, $SD = 3.46$ years). All participants gave written informed consent and received monetary compensation for their participation, which was approved by the Georgetown University Institutional Review Board.

Artificial Language

An artificial language (Brocanto2) rather than a natural language was examined for several reasons, including our ability to follow learning longitudinally to high proficiency, to control for multiple factors such as the amount and type of exposure, and to avoid various confounds such as similarity to the native language (see above). At the same time, because Brocanto2 follows universal requirements of natural languages, is fully productive, is actually spoken and comprehended, and is based on the artificial language Brocanto, which shows natural language brain patterns in both ERP and fMRI (Opitz & Friederici, 2003; Friederici et al., 2002), the results of this study are likely to generalize to natural languages.

The lexicon of Brocanto2 consists of a small number of nonwords with English pronunciation and phonotactics. It thus avoids phonological L1–L2 differences, which are a common source of difficulty in L2 acquisition. The language contains 13 lexical items: 1 article (*l-*), marked for gender (masculine *li*; feminine *lu*); 2 adjectives (*trois-*, *neim-*), each marked for gender (masculine *troise*/*neime*; feminine *troiso*/*neimo*); 4 nouns (*pleck, neep, blom, vode*), two of which are masculine and two feminine (the nouns are not overtly marked for gender, but their articles and adjectives must agree with them); 4 verbs (*klin, nim, yab, praz*); and 2 adverbs (*noyka, zayma*). Note that because Brocanto2 is presented solely auditorily, the orthographic representations presented here are provided solely for the reader. In contrast to English noun phrases, articles and adjectives in Brocanto2 are (a) postnominal (i.e., noun–[adjective]–determiner) and (b) morphologically marked so as to agree in gender with the noun to which they refer. Also unlike English, Brocanto2 sentences have a fixed subject–object–verb word order and have no morphological features on the verb. Adverbs, when used, immediately follow the verb. All the grammatical features of Brocanto2 are found in natural languages, such as Supyire (spoken in Mali), which has subject–object–verb word order, grammatical gender agreement, and postnominal adjectives and determiners (Carlson, 1994).

Each of the 1404 possible Brocanto2 sentences is meaningful in that it describes a move of a computer-based board game, which provided a context for the participants to use the artificial language; see Table 1 for an example of Brocanto2 sentence and Figure 1 for an example game board configuration.

Table 1. Example Correct and Violation Brocanto2 Sentences

Sentence Type	*Brocanto2 Stimuli*					
Correct sentence	*Blom*	*neimo*	*lu*	*neep*	*li*	*praz*
	Blom-piece	square	the	neep-piece	the	switch
	"The square blom-piece switches with the neep-piece."					
Word-order violation sentence	*Blom*	**nim*	*lu*	*neep*	*li*	*praz*
	Blom-piece	*capture	the	neep-piece	the	switch
	"The *capture blom-piece switches with the neep-piece."					

* denotes violation.

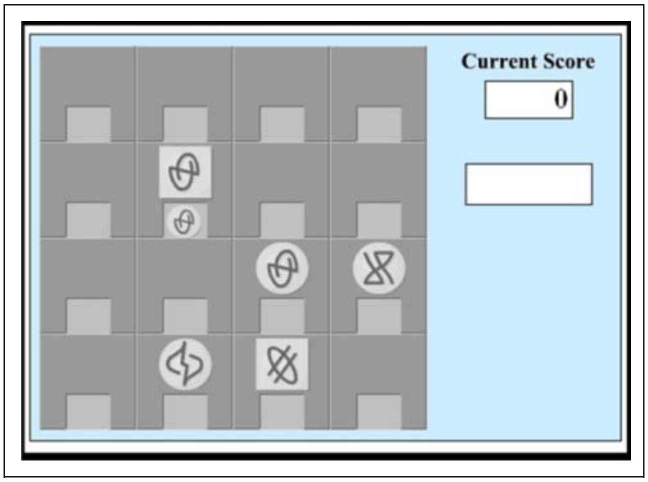


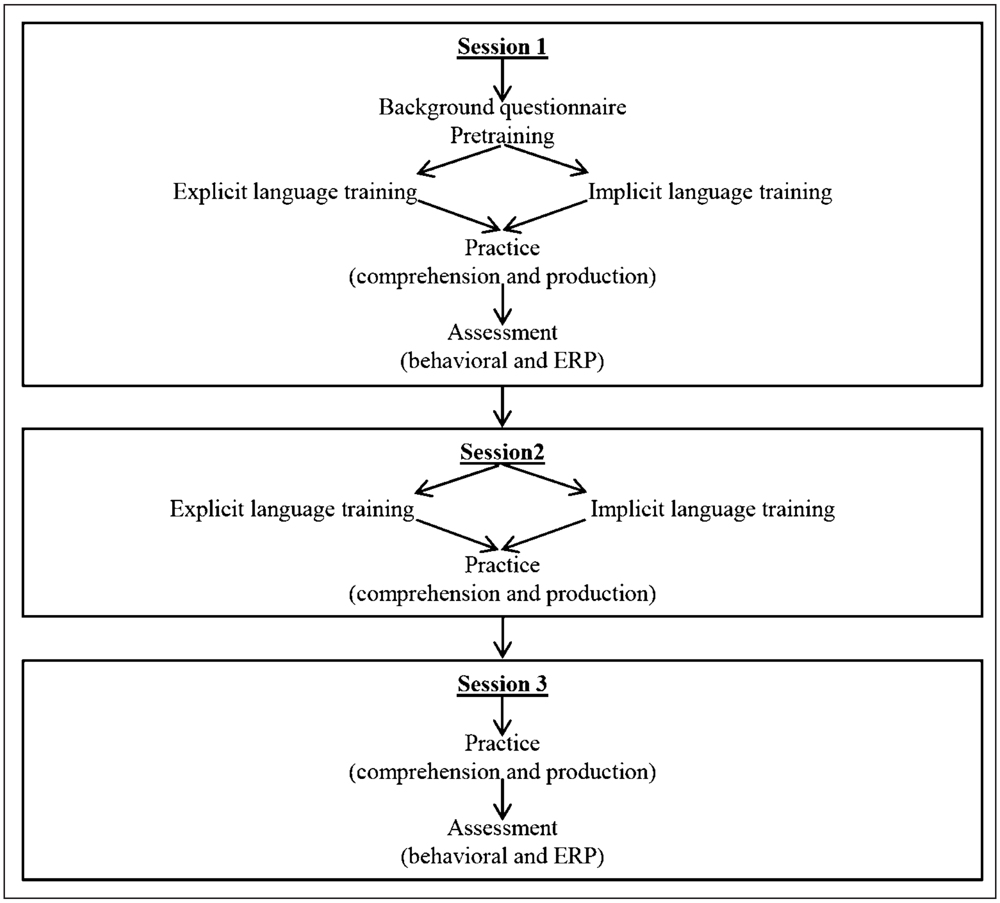
Figure 1. Computer-based game board. Game tokens are represented by visual symbols, which correspond to nouns in Brocanto2. The tokens can further be distinguished by their background shape—square or round—each of which corresponds to a Brocanto2 adjective. Players can move, swap, capture, and release tokens, with each of these actions corresponding to Brocanto2 verbs, as well as move them either horizontally or vertically (corresponding to Brocanto2 adverbs).

Procedure

The procedure for the current study consisted of training, practice, and assessment of Brocanto2 over the course of three experimental sessions (see Figure 2 for a schematic overview of the entire procedure). At the beginning of the study, participants responded to a background questionnaire and completed pretraining activities, in which they were given a brief introduction to the computer-based game and learned the names of the four game tokens (*pleck, neep, blom, vode*) to 100% accuracy (demonstrated by naming each token correctly three times). After completing pretraining, participants were presented with either an explicit or an implicit aural language training condition. The training conditions were designed to approximate real-world language learning settings to maximize the ecological validity of the training.

The explicit training condition provided input of a type similar to that found in traditional grammar-focused classroom settings, where learners are typically provided with metalinguistic information related to the functions and rules of aspects of the language, along with a few phrases and sentences that demonstrate the application of these rules. Thus, in this condition metalinguistic explanations were presented along with meaningful examples (see Appendix A). The metalinguistic explanations were structured around word categories, that is, around the nouns, articles, adjectives, verbs and adverbs of Brocanto2. For each word category, the explanation included information about its function (e.g., adjectives describe nouns), grammatical rules (e.g., adjectives agree with the gender of the noun that they modify), and word order rules (e.g.,

Figure 2. The experimental design consisted of three sessions during which background questionnaires, pretraining (learning the rules of the computer-based game, and the names of the four game tokens), explicit and implicit artificial language training, practice, and assessments were administered. Arrows indicate whether the subsequent experimental procedure was the same (downward and inward pointing arrows) or different (outward pointing arrows) for the explicit and implicit training conditions.



adjectives are always placed after the noun that they modify). Each metalinguistic explanation was accompanied by one or more meaningful examples (total of 33 examples). In total, 13.5 min of training was provided in the explicit condition.

The implicit condition provided the same amount of training, that is, 13.5 min. This condition was designed to represent more implicit language learning contexts, such as immersion settings, in which learners are exposed to a larger number of meaningful phrases and sentences, but receive little or no metalinguistic information. Thus the implicit training condition consisted only of meaningful examples (see Appendix B). Importantly, to match the amount of total training in the implicit and explicit conditions, the implicit condition contained not only the 33 meaningful examples presented in the explicit condition but also 94 additional meaningful examples to match the time of the metalinguistic explanations in the explicit condition. Crucially, this design allowed us to maintain equivalent training time between the explicit and implicit training conditions, which has not been systematically controlled in previous L2 research (see Introduction; Norris & Ortega, 2000). To summarize, the explicit and implicit training conditions were identical in the overall *amount* of training but differed in the *type* of training: metalinguistic explanations and meaningful examples in the explicit condition versus only meaningful examples in the implicit condition.

Other potential differences between the conditions were also eliminated or minimized: both conditions were computer controlled; both presented Brocanto2 sentences auditorily, starting with simple phrases and gradually moving to simple and then complex sentences; and neither provided English translations. In essence, the study allowed us to contrast explicit and implicit training while tightly controlling for multiple other variables—a design that would have been difficult, if not impossible, with a natural language.

After the initial explicit or implicit training session, participants in both groups practiced Brocanto2 in comprehension and production blocks, which were designed to approximate normal language use. Practice was identical for the two training groups. There were 44 practice blocks, with 20 trials (sentences and corresponding moves on the computer game board) in each block. Half of the blocks consisted of comprehension practice trials, in which participants listened to a prerecorded sentence in Brocanto2 and were asked to carry out the stated move on the screen using the computer mouse. The other half of the blocks consisted of production practice trials, in which participants watched a move displayed on the screen and had to describe it with a single oral sentence in Brocanto2. Comprehension and production alternated every two blocks. For both types of practice, correct/incorrect feedback was provided; this was identical for the two groups. This is consistent with feedback that occurs in both explicit (e.g., classroom) and implicit (e.g., immersion) input settings (Lyster & Mori, 2006; Lyster & Ranta, 1997). Thus, other than the crucial contrast between explicit and implicit training, all aspects of the experimental design, including practice, were identical between the two groups.

Participants continued with comprehension and production practice until they reached low proficiency, which was operationalized as accuracy significantly above chance on two subsequent comprehension practice blocks. Chance in each block was calculated as 45% correct, based on the number of correct moves of the total number of possible moves. The average score on these two comprehension practice blocks was indeed above chance for both the explicitly ($M = 0.63$, $SD = 0.17$) and implicitly ($M = 0.65$, $SD = 0.19$) trained groups ($t(28) = 0.232$, $p = .819$). When participants reached this level, the first ERP test session was administered (see below). All participants completed the initial round of training, practice, and low proficiency testing in one day (see Figure 2).

Participants returned for a second round of training followed by practice 1–4 days later ($M = 1.53$, $SD = 1.25$). Training was identical to the first round (same input and examples). Practice was also the same as in the first round, although with entirely new sentences, that is, that had not been presented before. Participants completed all blocks through block 36 in this round.

Finally, participants returned 1–5 days afterwards ($M = 2.35$, $SD = 1.41$), when they completed the remaining eight practice blocks. At this point (end of practice), all participants scored at 80% accuracy or above on comprehension practice. The average score on the final two comprehension practice blocks at the end of practice was around 95% for both groups (explicit: $M = 0.95$, $SD = 0.08$; implicit: $M = 0.94$, $SD = 0.10$; $t(28) = 0.783$, $p = .440$), and participants were considered to be at a high level of proficiency. Immediately after completing the final practice module, the second ERP test session was administered.

ERP Assessment

ERP assessment was carried out with 240 Brocanto2 sentences, including 40 sentences with a syntactic word order violation, and 40 matched correct control sentences (see Table 1 for examples). Word order violation sentences were created from each of the 40 correct sentences by replacing a word from one of the five word categories (e.g., noun, adjective, article, verb, and adverb) with a word of a different word category that violated the word order rules of Brocanto2. Thus, the correct and violation sentences differed *only* in this target (correct or violation) word, the onset of which served as the point of comparison for ERP analysis. To avoid confounds with specific words, word category or sentence position, violations were equally distributed over (a) the 14 words to the extent possible, (b) the five word categories, with each word category being replaced by each of the other word categories approximately twice (e.g., adjectives were never replaced by articles because that would not yield a word order violation and so were replaced by other categories three times), and (c) sentence positions to the extent possible, although violations never occurred on the first word of the sentence. Note that, for violations to be equally distributed across word categories, it was necessary for them to occur in sentence final position in the case when the violation was created on the adverb. In all other cases, sentence final violations were avoided. In summary, this *balanced* design ensured that across trials, the violation and control conditions did not differ with respect to either (i) the critical target words or (ii) the contexts preceding the target words, thus ruling out baseline problems as well as lexical confounds that are typically found in previous ERP work on word order violations (for a discussion see Steinhauer & Drury, in press). Additional violation and control sentences examining grammatical gender agreement and verb argument comprised the remaining 160 sentences. As these stimuli were motivated by somewhat different research questions, they are reported elsewhere (Morgan-Short, Sanz, Steinhauer, & Ullman, 2010; Morgan-Short, 2007); because they are informative to the current study, we also present them below (see Discussion).

Before ERP recording, participants were given instructions and a short practice session and were asked to minimize eye and body movements during sentence presentation. During ERP data collection, the following presentation sequence occurred for each sentence: First, a fixation cross appeared in the center of the screen simultaneously to the aural presentation of a Brocanto2 sentence (via ER-4 insert earphones; Etymotic Research, Inc.). The fixation cross remained for the duration of the sentence. Following Friederici et al. (2002), words were separated by a 50-msec interval of silence to establish acoustically identical baselines and an absence of coarticulation between words while allowing for relatively natural-sounding sentences. This approach to stimulus presentation minimizes prosodic context effects that potentially contribute to previous ERP data (Steinhauer & Drury, in press). Following the last word of each sentence, the fixation cross remained on the screen for an additional 500 msec, after which time it was replaced by the prompt "Good?" Participants had up to 5 seconds to make a judgment about whether the sentence was good or bad, indicated with the buttons of a computer mouse (left for good and right for bad). The next sentence and fixation cross were presented immediately after the response. Scalp EEG was continuously recorded in DC mode at a sampling rate of 500 Hz from 64 electrodes (extended 10–20 system) mounted in an elastic cap (Electro-Cap International, Inc., Eaton, OH), and analyzed using EEProbe software (Advanced Neuro Technology, Enschede, the Netherlands). Scalp electrodes were referenced to the left mastoid, and impedances were kept below 5 kΩ. The vertical EOG was recorded with two electrodes placed above and below the right eye, and the horizontal EOG was recorded with two electrodes placed on the right and left canthi. The EEG was amplified by Neuroscan SynAmps^2 amplifiers and filtered on-line with a band-pass filter (DC to 100 Hz, 24-dB/octave attenuation). Off-line, the EEG was filtered with a 0.16–30 Hz band-pass filter. Data from all target words free of artifacts greater than 40 μV in the EOG and greater than 75 μV in EEG were included in the analysis.

Statistical Analysis

To compare the groups' performance, participants' behavioral responses to the on-line judgment task were transformed to d' scores. Differences in the ability to discriminate correct and violation sentences were examined by submitting d' scores for each participant to a 2 × 2 ANOVA with test session (low proficiency, high proficiency) as a repeated factor and group (explicit, implicit) as a between-subject factor.

For ERP analysis, EEG data time-locked to the onset of the violation or matched control target word were averaged for each participant for an array of 24 lateral electrodes using a 200-msec prestimulus baseline. These electrodes covered six levels of anterior/posterior distribution: F5, F3, F4, F6 (anterior-1); FC5, FC3, FC4, FC6 (anterior-2); C5, C3, C4, C6 (central-1); CT5, CP3, CP4, CT6 (central-2); P5, P3, P4, P6 (posterior-1); and PO3, OL, OR, PO4 (posterior-2). Within each of these levels, the electrodes also covered two levels of hemisphere (right, left) and two levels of laterality (lateral, medial). Additionally, three midline electrodes (Fz, Cz, Pz) were analyzed. Together, this array covers the typical scalp distribution of the language-related ERP components of interest here. Artifact-free target words were analyzed regardless of whether participants' on-line judgments were correct or not. This approach, which is common in L2 ERP research (Frenck-Mestre, Osterhout, McLaughlin, & Foucart, 2008; Chen et al., 2007; Ojima et al., 2005; Friederici et al., 2002; Weber-Fox & Neville, 1996), was deemed appropriate because (a) ERP effects have been found in L2 even when learners do not accurately judge stimuli (Tokowicz & MacWhinney, 2005; McLaughlin et al., 2004); (b) the lower accuracy rates at low proficiency would have resulted in a lower signal to noise ratio, as compared with high proficiency; and (c) visual inspection of waveforms reflecting target items to which participants had responded correctly, and waveforms reflecting all target items (i.e., those used here) revealed highly similar patterns. Individual ERPs were entered into separate grand ERP averages for the explicitly and implicitly trained groups. Time windows were selected on the basis of previous research and visual inspection of the grand averages: 150–350 msec for early ANs, 350–700 msec for the AN and N400, and 700–900 msec for the P600.

Mean amplitudes for each time window were analyzed using a global ANOVA with the between-subject factor Group (explicit, implicit); the within-subject factors Test Session (low proficiency, high proficiency) and Violation (correct, violation); and the distributional factors Laterality (lateral, medial), Hemisphere (right, left), and Anterior/Posterior (anterior-1, anterior-2, central-1, central-2, posterior-1, posterior-2). When evaluating the Anterior/

Posterior factor (which included more than one degree of freedom) the Greenhouse–Geisser correction was applied (corrected p values are reported). In all cases, any global ANOVA that yielded any significant ($p < .05$) interaction including the factor violation was followed up with step-down ANOVAs to clarify the nature of the interaction. Similar analyses were also carried out for the midline electrodes, but without the factors Laterality and Hemisphere. We report significant ($p < .05$) violation main effects and interactions from each global ANOVA as well as lower-level group-specific or distributional violation effects revealed by significant step-down analyses. Results of the midline analysis are reported only when they revealed effects that were not evidenced in the lateral analyses.

RESULTS

Behavioral Data

The explicit and implicit groups did not differ in the number of practice blocks or the amount of practice time needed to reach low proficiency nor did they differ in the number of blocks or the amount of time between the attainment of low proficiency and end of practice (ps > .6; over both groups, means of 6.9 blocks and 48.23 min to reach low proficiency; from low proficiency to end of practice, means of 37.1 blocks and 161.73 min).

Analysis of participants' performance on the on-line judgment task revealed a main effect of test session [$F(1, 28) = 76.18, p < .001$], with performance improving between low and high proficiency, no main effect of group ($F < 1$), and a significant Test Session × Group interaction [$F(1, 28) = 4.67$, $p = .039$], which reflected a larger performance improvement between low and high proficiency for the implicit group as compared with the explicit group—although both groups in fact reached high proficiency by the second test session and the two groups did not differ significantly in performance at either low or high proficiency (see Figure 3).

ERP Data

Visual inspection of the ERP voltage maps and waveforms (see Figure 4) suggests an N400 for the implicit group at low proficiency, but no clear effects for the explicit group. At high proficiency, the implicit group appears to show an AN followed by a P600 and a late AN, whereas the explicit group displays an anterior positivity followed by a P600. Statistical analysis showed that these effects were reliable.

In the 150–350 msec (early AN) time window, the global ANOVA produced only a Group × Violation interaction [$F(1, 28) = 5.85$, $p = .022$]. Step-down analyses revealed a main effect of violation for only the implicit group [$F(1, 13) = 7.06, p = .020$], reflecting a negativity in this training group over both the low- and high-proficiency test sessions. Inspection of the voltage maps for this time window for the implicit group (see Figure 4C and D) suggests that this shared negativity may reflect the emergence of two different effects at low and high proficiency, which become clearer in the subsequent time window. Indeed, ANOVAs specific to each test session in the implicit group suggest that this negativity has a different distribution at low and high proficiency. At low proficiency, the midline analysis revealed a main effect for Violation [$F(1, 13) = 6.03$, $p = .029$], and the lateral analysis revealed a Violation × Laterality × Hemisphere interaction [$F(1, 13) = 6.45$, $p = .025$], for which all follow-ups were not significant. At high proficiency, the only main effect or interaction to

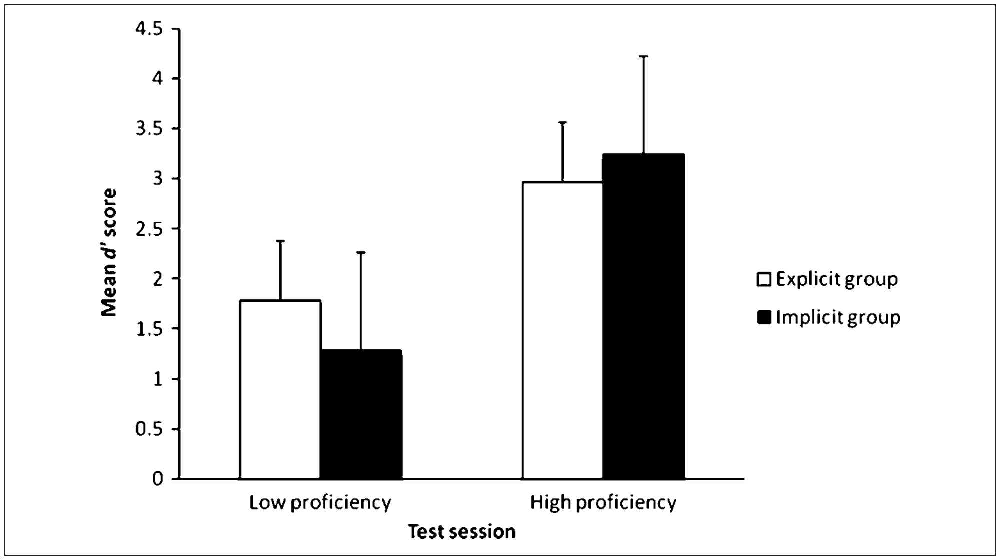


Figure 3. Mean d' scores and standard errors for the explicitly trained and implicitly trained participant groups at low proficiency and at high proficiency. Paired t tests on d' scores motivated by a Group × Test Session interaction (see Results) indicated that the two groups did not differ in their ability to distinguish correct and violation sentences, at either low proficiency ($t(28) = 5.61, p = .579$) or high proficiency ($t(28) = 1.24$, $p = .226$). Both groups improved from the first to the second test session (explicit: $t(28) = 4.80, p < .001$; implicit: $t(28) = 7.47, p < .001$), although the improvement was larger for the implicit than the explicit group, as indicated by the Group × Test Session interaction. At high proficiency, the d' scores of both groups were above 2.5, which corresponds roughly to a proportion correct of 0.90 (Macmillan & Creelman, 2005), indicating that both groups had reached a high level of proficiency.

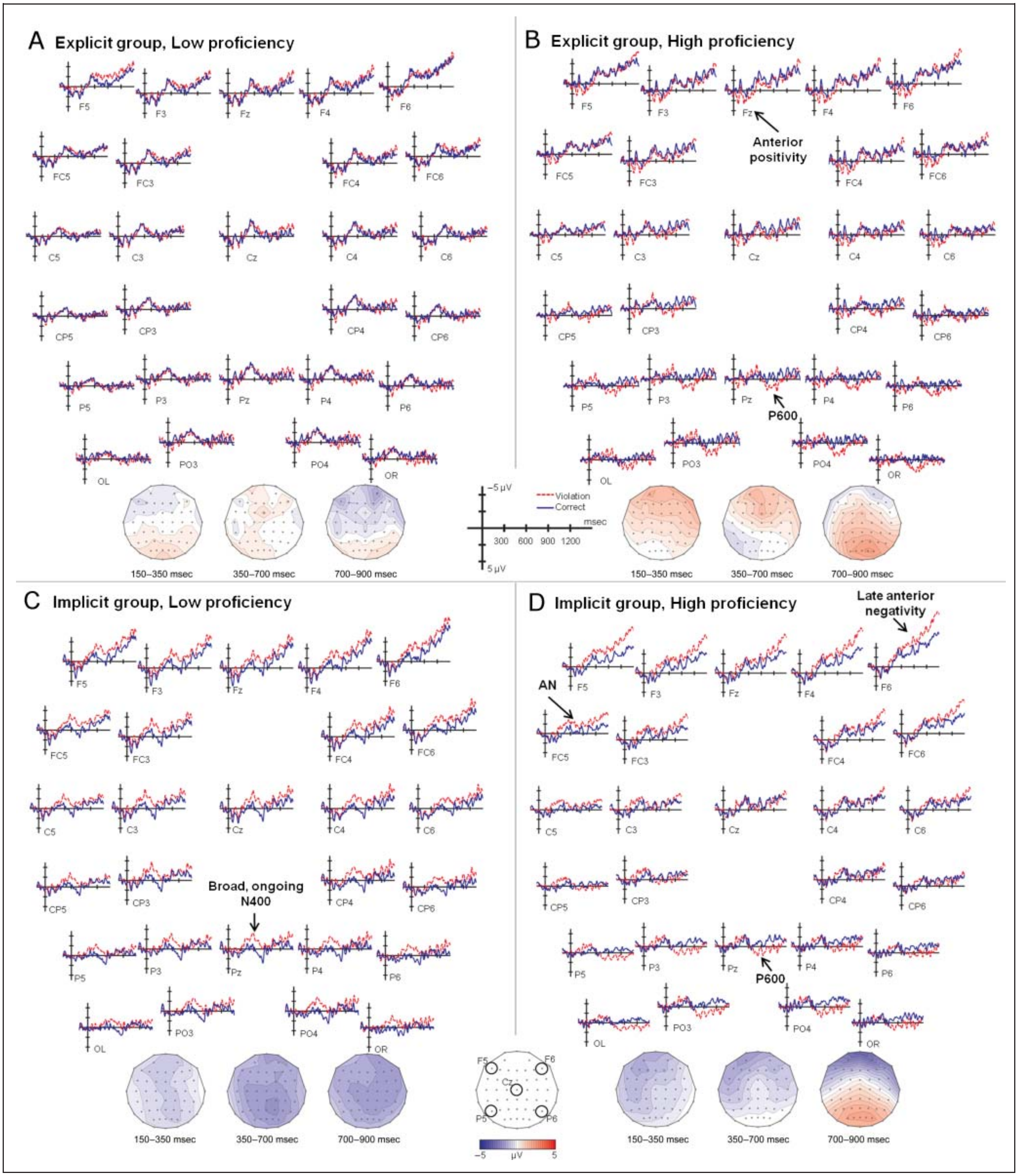


Figure 4. Voltage maps and waveforms reflecting the difference between correct and violation sentence grand average ERPs. (A) Explicitly trained learners at low proficiency do not evidence any significant ERP effect. (B) Explicitly trained learners at high proficiency show an anterior positivity followed by a P600. (C) Implicitly trained learners at low proficiency show a broad, ongoing N400. (D) Implicitly trained learners at high proficiency show an AN followed by a P600 and a late AN. Voltage map coloration indicates amplitude differences between correct and violation waveforms.

reach significance was a Violation × Hemisphere interaction [$F(1, 13) = 5.90, p = .030$], which was driven by a main effect for violation in the left hemisphere [$F(1, 13) = 6.07$, $p = .028$] but not in the right hemisphere. Although these differences in distribution were not large enough to elicit any interactions that included Test Session in the global ANOVA, they are suggestive of the emergence of different ERP patterns at low and high proficiency in the implicit group.

In the 350–700 msec (AN and N400) time window, the global ANOVA revealed a main effect of Violation [$F(1, 28) = 4.54$, $p = .042$]. This negativity was qualified by a two-way Group × Violation interaction [$F(1, 28) = 6.08$, $p = .020$] and a four-way Group × Test Session × Violation × Anterior/Posterior interaction [$F(5, 140) = 3.79$, $p = .048$]. Step-down analyses based on the four-way interaction revealed two distinct negative ERP effects, only in the implicit group: (a) an N400 at low proficiency, present at posterior electrodes [posterior-2: $F(1, 13) = 7.25$, $p < .019$] and (b) an AN at high proficiency, most prominent at anterior sites, and extending toward central sites [anterior-1: $F(1, 13) = 9.38$, $p < .009$; anterior-2: $F(1, 13) = 8.28$, $p < .013$; central-1: $F(1, 13) = 7.84$, $p < .015$; central-2: $F(1, 13) = 4.78$, $p < .048$]. Analysis of the midline electrodes produced an additional finding: The follow-up analyses of a midline Group × Test Session × Violation × Anterior/Posterior interaction [$F(2, 56) = 4.85$, $p = .022$] revealed an anterior positivity for the explicit group at high proficiency [Anterior mid: $F(1, 15) = 5.81$, $p < .029$].

Thus, for these earlier time windows, the results show that, at low proficiency, the implicit group elicited an N400 (Figure 4C), whereas the explicit group elicited no effects (Figure 4A). At high proficiency, the implicit group elicited an AN (Figure 4D), whereas the explicit group exhibited an anterior positivity (Figure 4B).

In the 700–900 msec (P600, late AN) time window, we found a two-way Violation × Anterior/Posterior interaction [$F(5, 140) = 10.69$, $p = .002$], a three-way Test Session × Violation × Anterior/Posterior interaction [$F(5, 140) = 11.65$, $p < .001$], and a four-way Group × Test Session × Violation × Anterior/Posterior interaction [$F(5, 140) = 5.04$, $p = .017$]. Step-down analyses based on the four-way interaction confirmed three distinct ERP components for the implicit group: an ongoing N400 [central-2: $F(1, 13) = 9.81$, $p = .008$] at low proficiency and both a P600 [posterior-1: $F(1, 13) = 5.89$, $p = .031$; posterior-2: $F(1, 13) = 7.61$, $p = .016$] and a late AN [Anterior 1: $F(1, 13) = 5.82$, $p = .031$] at high proficiency. The explicit group, by contrast, showed neither an N400 nor a late AN, although a P600 was observed at high proficiency [posterior-1: $F(1, 15) = 6.17$, $p = .025$; posterior-2: $F(1, 15) = 6.90$, $p = .019$].

In summary, for this later time window, at low proficiency the implicit group showed an ongoing N400 (Figure 4C), whereas the explicit group displayed no effects (Figure 4A). At high proficiency, the implicit group showed both a P600 and a late AN (Figure 4D), whereas the explicit group showed only a P600 (Figure 4C).

DISCUSSION

We used an artificial language paradigm to examine longitudinally, at both low and high proficiency, whether explicit or implicit training conditions differentially affect neural (ERP) and behavioral (performance) measures of L2 syntactic processing. Although explicitly and implicitly trained participants showed statistically indistinguishable performance at both low and high proficiency, real-time electrophysiological measures revealed striking differences between the groups' neural activity. Most importantly, only the implicit training condition showed the full spectrum of ERP components typically found for L1 syntactic processing.

The finding that performance did not differ between the two training groups at either low or high proficiency indicates that the ERP differences cannot be explained by performance differences. It also suggests that, at least in this paradigm, both training methods yield comparable performance outcomes. Nevertheless, the group by test session interaction on performance indicates that implicit training may be better than explicit training at realizing gains toward the attainment of high proficiency. This finding is more in line with the popular view that immersion is superior to classroom training for reaching high proficiency than are previous behavioral studies that have suggested an advantage for explicit training (see Introduction). The difference between these results and those of previous studies may be because of the important methodological differences between them.

The Type of Training Shapes the Neurocognition of L2

The fact that the ERP patterns differed between the explicit and implicit training groups, although performance between them did not, validates the use of neural measures and demonstrates that differential L2 training can produce differences in brain processing that are not reflected by behavioral measures.

The specific ERP components found in the implicit group in each of the two test sessions provide direct insight into the neurocognitive processes that the implicitly trained L2 learners relied on as they proceeded from low to high proficiency. The N400 observed at low proficiency supports the view that at early stages of L2 learning, (morpho)syntactic processing relies, at least in part, on lexical/semantic mechanisms and declarative memory (Clahsen & Felser, 2006; Ullman, 2001, 2005) and shows moreover that this reliance can result from implicit training. The finding that, at high proficiency, implicit learners showed an AN–P600 biphasic response, as well as a late AN, provides evidence that implicit training can in fact lead to L1-like brain processing for syntax: These ERP components have repeatedly been found in L1, and no additional components are generally elicited by native speakers in response to (morpho)syntactic violations (Steinhauer & Connolly, 2008). More specifically, given the prevailing interpretation of these components, the findings suggest that, with implicit training, syntactic processing can come to rely on the same biphasic mechanisms found in L1: rule-governed automatic structure building, which may involve the engagement of procedural memory, followed by controlled structural reanalysis, accompanied by an increasing demand on working memory. Alternatively, the two ANs may reflect a single process, which may represent the maintenance of unintegrated linguistic input in phonological working memory (Steinhauer & Drury, in press). Finally, the findings of an N400 at low proficiency, together with the AN–P600 pattern accompanied by a late AN at high proficiency, show that the implicitly trained group experienced a qualitative shift in neurocognitive processing while advancing from low to high proficiency.

The explicit group did not show this pattern. The lack of any ERP effects at low proficiency suggests that explicit training does not lead to a systematic and consistent reliance of syntax on either lexical/semantic or L1-like grammatical processes at low proficiency nor does their syntax rely on any other neurocognitive processes that would be reflected in ERP components. One possible explanation for this null effect is that explicit training led to increased variability (e.g., between participants) in the types of explicit cognitive strategies and/or the timing of ERP components; such variability could wash out any clear components in the waveforms, leading to a lack of reliable statistical differences. At high proficiency, the data for the explicitly trained learners are somewhat more revealing. The presence of a P600 without a preceding AN suggests that, although explicit training is sufficient to develop the ability for structural reanalysis that may be under conscious (explicit) control, it does not reliably lead to the automatic early syntactic processing that is found in L1 and may depend on procedural memory. The interpretation of the absence of a late AN is less clear. It may suggest that any controlled reanalysis did not depend more on working memory in the violation than correct condition, possibly because both conditions required equal engagement of working memory. Alternatively, if late ANs represent the continuation of earlier ANs (Steinhauer & Drury, in press), then the absence of both together is not surprising. The anterior positivity found at high proficiency for the explicit group might in part reflect attentional mechanisms, which are thought to drive the early fronto-central positivities that represent the P3a component (Polich, 2007). Indeed, the P3a has been reported in at least one other ERP violation study of L2 grammar (Mueller, Oberecker, & Friederici, 2009). Interestingly, studies of L2 development show that explicit training conditions are more effective than implicit training conditions in directing learners' attention to L2 forms (Leow & Bowles, 2005; Sanz & Morgan-Short, 2005). Thus, this positivity might reflect a reliance on domain-general attentional mechanisms rather than the syntactic or lexical/semantic processing that is typical for native speakers and, apparently, for implicit learners of an L2. This speculative interpretation may warrant investigation in future studies.

The results reported here can be compared with those reported by Morgan-Short et al. (2010), which examined different types of violations in the exact same study—that is, with the same participants, training, and practice. As mentioned above, the participants in the present study were exposed not only to word order violations but also to (noun–article and noun–adjective) gender agreement violations, which are discussed in Morgan-Short et al. (2010), as well as violations of verb argument structure (although these have not yet been reported in a published study, so are not presented here). The gender agreement violations showed both similarities and differences to the word order violations. As with the word order violations, both the explicitly and implicitly trained groups improved on their ability to judge (both types of) gender agreement violations between low and high proficiency but did not differ in their performance at either proficiency level. For ERPs, at low proficiency, the implicit group showed N400s not only for word order violations but also for both types of agreement violations. The explicit group, by contrast, showed an N400 only for noun–adjective violations but not for either word order or noun–article violations. At high proficiency, however, word order and agreement violations evidenced quite different patterns. Unlike word order violations, which yielded an AN and a late AN only in the implicit group, agreement violations showed the same effects in both training groups at high proficiency, with P600s (no ANs) in both groups for noun–article violations, and N400s in both groups for noun–adjective violations. Overall the results from the word order and gender agreement violations suggest the following. First, at low-proficiency implicit, but not explicit, training seems to reliably lead to N400s and a reliance of grammar on lexical/semantic processing and declarative memory. Second, at high proficiency, both the type of linguistic structure and the type of training appear to influence the nature of processing, because for agreement violations, the nature of the violation (and not the type of training) determined ERP outcomes, whereas for word order violations, the type of training was critical. Finally, note that the absence of ANs for gender agreement, as well as the presence of P600s for noun–article agreement and even of N400s for noun–adjective agreement, are broadly consistent with previous studies of gender agreement violations in L1 (Morgan-Short et al., 2010). Thus together, the results of the agreement and word order violations suggest that L1-like brain processing of (morpho)syntax can be achieved by L2 learners and that this achievement depends in some cases (word order) but not others (gender agreement) on the type of training.

It is more difficult to compare the findings of the present study with other neurocognitive research, because previous studies have not specifically controlled for or contrasted explicit and implicit training and do not consistently report the proportion or amounts of such training. Nevertheless, some studies can provide certain insights. First, although the finding of N400s for morphosyntactic processing after a small amount of classroom training (4 weeks) in French (Osterhout et al., 2008) further supports the dependence of (morpho)syntax on lexical/semantic processing and declarative memory at low proficiency, it also supports the view that explicit training (classroom-based) may, in some cases, lead to this outcome. Second, the P600 that was elicited by the high-proficiency explicit learners is consistent with P600s found after somewhat greater amounts of classroom training (4–8 months) in French (Osterhout et al., 2008). Third, the biphasic AN–P600 pattern observed here for implicitly trained learners at high proficiency is compatible with the results from a study of word order violations in Brocanto, in which participants were trained largely (although not completely) implicitly, also yielding an AN–P600 pattern at high proficiency (Friederici et al., 2002); low proficiency was not examined. Additionally, all three studies that reported AN–P600 biphasic responses for (morpho)syntactic violations in high-proficiency late learners of natural languages (see Introduction) found this response in participants who were living in an immersion environment (Gillon Dowens et al., 2009; Steinhauer et al., 2009; Hahne et al., 2006). Finally, the observed shift from an N400 at low proficiency to an AN–P600 at high proficiency seems consistent with an fMRI study reporting an analogous neurocognitive shift (Opitz & Friederici, 2003). In this study, participants were trained with visually presented Brocanto sentences (with no associated meanings). They showed initial activation in declarative memory structures, which decreased over the course of training, whereas activation in procedural memory structures increased. However, like all previous neurocognitive studies, explicit and implicit inputs were not specifically controlled for or contrasted, precluding conclusions about the role of training in these outcomes. The data from the present study suggest that future neurocognitive studies of L2 learning should at least clearly report, if not control for, both the amount and the type of L2 training.

Theoretical Implications

The results from the current study have implications for neurocognitive theories of L2 and demonstrate that these theories should take the type of L2 training into account. The attainment of L1 ERP components by the implicit group does not appear to be compatible with the view that adult-learned L2 always relies on entirely different mechanisms than L1 and that it is necessary to learn language during the "critical period" to attain native-like brain processing (Bley-Vroman, 1989). The N400 displayed by the implicit group at low proficiency, by contrast, seems inconsistent with models hypothesizing that L2 depends on the same neurocognitive mechanisms as adult L1 (Abutalebi, 2008; Indefrey, 2006). Rather, the data provide further support for the neurocognitive perspective that L2 grammar, at least in part, depends on lexical/semantic processes and declarative memory at low proficiency but can come to rely on native-like grammatical processes and procedural memory at high proficiency (Steinhauer et al., 2009; Clahsen & Felser, 2006; Ullman, 2001, 2005). Crucially, the data also show that this outcome can interact with the type of condition under which the language is learned, with only implicit training leading to these L1 processes, in at least some cases. Thus the data suggest a refinement of this neurocognitive theory, in that the "proceduralization" of grammar may, in some cases, benefit from learning under implicit, immersion-like conditions.

This result is consistent with learning in other cognitive domains, such as probabilistic classification or rule learning: both the declarative and procedural memory brain systems can learn probabilistic patterns and to similar levels of performance, but only certain training conditions, in particular those in which explicit knowledge is minimized, lead to a processing dependence on procedural memory (Foerde et al., 2006). Also like the present study, such probabilistic learning has been found to show an early dependence on declarative memory and a later dependence on procedural memory under learning conditions that promote learning in the latter system (Poldrack et al., 2001). These parallel findings further strengthen the dependence of language on declarative and procedural memory (Ullman, 2001, 2004, 2005) and suggest that investigations of language can inform other domains that depend on these memory systems and vice versa.

Future Directions

The study brings up a number of issues that warrant examination in future experiments. First, in this study and in Morgan-Short et al. (2010), we focused on certain syntactic structures that have been well studied in ERP research. It remains to be seen whether the neurocognition of other aspects of syntax or of morphology or phonology are differentially affected by explicit and implicit training. Second, whereas in the present study, the L2 (Brocanto2) differed from the L1 (English) in crucial respects (word order and gender agreement), future studies may reveal whether grammatical (dis)similarity between L1 and L2 may interact with the type of training. For example, given that some research suggests that L1/L2 structural similarity can lead to more native-like ERP patterns in the L2 (Sabourin & Stowe, 2008; Tokowicz & MacWhinney, 2005), it is possible that the type of training might be less important in such situations, because even explicitly trained learners might achieve L1-like brain processing. Third, further studies can tell us whether additional training or practice, beyond what was examined here, might lead to different neural or behavioral outcomes. For example, the bilaterally distributed AN in the implicit group might become left-lateralized with further practice and increased proficiency (indeed, the left lateralization of the negativity in an earlier time window is consistent with this possibility). Additionally, it remains possible that explicit training might eventually lead to native-like neural processing—or not. Fourth, different kinds of explicit or even implicit training might lead to different outcomes. For example, perhaps other kinds of explicit training (e.g., with feedback containing metalinguistic explanations) might lead to more native-like brain processing.

Fifth, future research may elucidate precisely which aspects of explicit and implicit training led to the observed results. For example, it is possible that the provision of additional exemplars in the implicit training condition, which were provided to match the amount of time dedicated to explicit instruction in the explicit training group, contributed to the more native-like ERP patterns in the implicit group. However, both the explicitly and implicitly trained learners were exposed to an additional 440 sentences during comprehension practice, so in fact the total number of examplars presented to the explicit group (473 = 33 examplars given to both training groups + 440 comprehension practice items) was only 17% lower than the total number presented to the implicit group (569 = 33 examplars given to both training groups + 96 examplars given only to the implicit group + 440 comprehension practice items). Therefore, the difference in training examplars between the two groups does not seem to be a likely explanation for the observed effects. Alternatively, the provision of explicit information may actually impede the development of native-like processing. Indeed, an analogous effect has been observed in other cognitive domains, such as sequence learning, in which an explicit training condition actually seems to suppress implicit (procedural) learning (Fletcher et al., 2005). The examination of this phenomenon in language seems warranted.

Sixth, the current study was limited to examining the effects of explicit and implicit training conditions on L2 performance and processing. It does not speak to whether learners engaged in explicit or implicit *learning* processes or if they acquired explicit or implicit *knowledge*. Seventh, it remains to be seen whether the results obtained here generalize to natural languages. The present study was designed to maximize this likelihood, because Brocanto2 follows language universals, is presented auditorily, is actually spoken and comprehended, is learned to high levels of proficiency, and shows natural-language-like brain patterns. However, further studies are needed to test its generalizability. Thus, like other simplified models of complex systems in science (e.g., animal models of human phenomena), using an artificial language allows us to rapidly and reliably (avoiding confounds) identify the factors or mechanisms of interest, after which one can focus on directly testing these already-identified factors and mechanisms in the slower and more difficult examination of the full complex system of interest, in this case natural language.

Conclusion

In summary, in this study learning under an implicit input condition designed to approximate immersion led to the full spectrum of native-like brain patterns for aspects of language processing (AN–P600 biphasic pattern, accompanied by a late AN), whereas learning under an explicit input condition designed to approximate traditional classroom settings did not (P600 only). Thus, the study suggests that, at least in certain cases, the attainment of L1 neurocognitive mechanisms in second language acquisition appears to depend not only on the level of proficiency but also on the conditions under which the L2 was learned.

APPENDIX A

Example Section from Explicit Training Condition

The example section just below provides metalinguistic information and meaningful examples related to Brocanto2 word order for subjects, objects, and verbs. Note that the text shown below was presented aurally. During the aural presentation of examples, corresponding game constellations, which are shown here in bold, were presented visually on the computer screen.

> In Brocanto2, both the subject and the object are placed before the verb. The subject occurs first and the object occurs second. Thus, the word order for Brocanto2 sentences is subject–object–verb. Now listen to a few examples.
>
> - **pleck li vode lu praz**
>
> In this example, we first state the subject, *pleck li*. This noun is doing the action. Second, we state the object, *vode lu*. This noun is receiving the action. Finally, at the end of the sentence you find the verb, *praz*. Listen to the example again.
>
> - **pleck li vode lu praz**
>
> Here's another example:
>
> - **pleck li blom lu nim**
>
> In this example, *pleck li* is the subject and comes at the beginning of the sentence. *Blom lu* is the object and is placed after the subject. *Nim* is the verb and is found after the object. Here are more examples for you to listen to:
>
> - **vode lu neep li praz**
> - **neep li pleck li yab**
> - **blom lu pleck li praz**

APPENDIX B

Example Section from Implicit Training Condition

The example section just below provides meaningful examples related to aspects of Brocanto2 word order. All examples were aurally presented together with visually presented corresponding game constellations. Note that "…" indicates that additional examples were provided.

> **pleck li vode lu praz**
> **vode lu neep li praz**
> **blom lu pleck li praz**
> **neep li blom lu praz**
> **…**

vode lu nim
vode lu neep li nim
pleck neime li nim
pleck li blom lu nim
…
neep li yab
blom lu pleck li yab
blom lu pleck li yab
blom lu yab
…

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Author Note: Overall, K. M. S. and K. S. contributed equally to this study and should both be considered first authors. K. M. S., K. S., C. S., and M. T. U. all contributed to the design of the experiment and the interpretation of the data. K. M. S. developed the materials together with K. S., and conducted the experiment and analyzed the data. K. S. and M. T. U. supervised the data analysis. K. M. S. and M. T. U. wrote the manuscript, which was extensively reviewed by K. S. and C. S.

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