Morphological Processing in a Second Language: Behavioral and Event-related Brain Potential Evidence for Storage and Decomposition

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Abstract

■ This study reports the results of two behavioral and two event-related brain potential experiments examining the processing of inflected words in second-language (L2) learners with Russian as their native language. Two different subsystems of German inflection were studied, participial inflection and noun plurals. For participial forms, L2 learners were found to widely generalize the *-t* suffixation rule in a nonce-word elicitation task, and in the event-related brain potential experiment, they showed an anterior negativity followed by a P600—both results resembling previous findings from native speakers of German on the same materials. For plural formation, the L2 learners displayed different preference patterns for regular and irregular forms in an off-line plural judgment task. Regular and irregular plural forms also differed clearly with regard to their brain responses. Whereas overapplications of the *-s* plural rule produced a P600 component, overapplications of irregular patterns elicited an N400. In contrast to native speakers of German, however, the L2 learners did not show an anterior negativity for *-s* plural overapplications. Taken together, the results show clear dissociations between regular and irregular inflection for both morphological subsystems. We argue that the two processing routes posited by dual-mechanism models of inflection (lexical storage and morphological decomposition) are also employed by L2 learners. ■

INTRODUCTION

Previous research indicates that inflectional morphology is an area of specific difficulty for adult second-language (L2) learners. L2 learners are said to use inflectional morphemes in an unsystematic fashion (Meisel, 1991) and reduced morphological paradigms (Klein, 1986). Some researchers (Prévost & White, 2000; Haznedar & Schwartz, 1997) speculate that the adult L2 learners' difficulties with inflectional morphology might be because of processing reasons. However, the details of L2 morphological processing have not been studied by these researchers. An interesting hypothesis as to how L2 processing might differ from native language (L1) processing has been advanced by Ullman (2001) from the perspective of dual-mechanism models of morphology (see, e.g., Clahsen, 1999; Pinker, 1999, for reviews). He argues that processing one's native language involves two different brain memory systems, a lexical store of memorized inflected words that depends upon declarative memory and is rooted in temporal lobe structures, and a mental grammar which includes combinatorial rules and is rooted in frontal brain structures. Given these assumptions, Ullman (2001) claims that L2 processing and representation is largely dependent upon the lexical memory system and invokes grammatical computation to a much lesser extent than L1 processing. He further assumes that reliance on the procedural memory system should increase with practice (Ullman, 2004). For morphological processing, this means that L2 learners mainly rely on full-form storage of inflected words, whereas morphological decomposition is underused or even absent in L2 processing of inflected words, and this might perhaps be the reason for why inflectional morphology is hard for L2 learners. Unfortunately, however, there is very little empirical evidence for these claims, and the details of how adult L2 learners process inflected words remain largely unknown.

With respect to L1 processing, experimental studies using a range of different psycholinguistic methods and techniques have led to a number of consistent and replicable results on how morphologically complex words are processed in one's native language, for example, frequency effects for inflected word forms in lexical decision tasks and stem-priming effects for regularly inflected word forms in different kinds of priming experiments. The theoretical interpretation of these and other results has been the subject of a controversy between associative single-mechanism models and a family of dual-mechanism models of inflection. A detailed review of this controversy is beyond the scope of

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the present article. It is, however, important to provide a brief summary of previous event-related brain potential (ERP) studies on morphological processing in adult native speakers.

Replicable ERP effects have been found in studies of inflectional morphology, in German (Lück, Hahne, Friederici, & Clahsen, 2001; Penke et al., 1997; Weyerts, Penke, Dohrn, Clahsen, & Münte, 1997), English (Münte, Say, Schiltz, Clahsen, & Kutas, 1999; Newman, Izvorski, Davis, Neville, & Ullman, 1999), Catalan (Rodriguez-Fornells, Clahsen, Lleo, Zaake, & Münte, 2001), Italian (Gross, Say, Kleingers, Münte, & Clahsen, 1998), and Spanish (Rodriguez-Fornells, Münte, & Clahsen, 2002). As the present study examines German as a target language, our focus here is on the three German ERP violation studies. Two types of violation were tested in these studies, (a) *regularizations*, formed by adding a regular suffix to a verb or noun that requires an irregular one, (b) *irregularizations*, in which a verb or noun that takes the regular default suffix appeared with an incorrect (irregular) ending. Penke et al. (1997) examined participle formation in three experiments, Weyerts (1997) and Lück et al. (2001) noun plurals. Penke et al. and Weyerts et al. presented their stimuli visually, Lück et al. auditorily. In all these experiments, an anterior negativity between 300 and 800 msec was found for regularizations (which was larger over the left than over the right hemisphere). Moreover, Lück et al. found a centroparietally distributed positivity (P600) in the 800- to 1200-msec time window for regularizations. For irregularizations, both the visual and the auditory studies on plurals elicited an N400-like negativity compared with their correct counterparts. These results were interpreted as supporting a dual-mechanism account of morphological processing. From this perspective, regularizations are combinatory violations, that is, misapplications of the participle *-t* or the plural *-s* to (irregular) verbs or nouns that would normally block these rules, to produce illegal stem + affix combinations. By contrast, irregular inflection is based on full-form storage, and misapplications of irregular inflection produce pseudowords, as suggested by the N400 effect for (plural) irregularizations.

In contrast to the rich experimental literature on L1 morphological processing, very little is known about how adults process inflected words in an L2. There are three L2 studies employing speeded production or grammaticality judgment tasks (Brovetto & Ullman, 2001; Beck, 1997; Lalleman, van Santen, & van Heuven, 1997). The findings from these studies are inconsistent and partly surprising. Although the native speaker controls showed a consistent response-time advantage for high-frequency irregulars (but not for high-frequency regulars) in all experiments, most studies failed to replicate this contrast for the L2 learners. Only Brovetto and Ullman (2001) obtained the same significant frequency effect for irregulars in L2 learners as in native controls. The L2 learners' results on regulars were even more inconclusive. Given the inconsistencies across and even within studies, any general conclusions would appear to be premature. Clearly, more research on L2 morphological processing is needed.

Given the sensitivity of ERPs as a distinctive neurophysiological measure of syntactic and lexical processes, we made use of this technique to further investigate how L2 learners process regular and irregular inflection. We investigated two inflectional systems of German, participle formation and noun plurals, which both contain regular and irregular forms but differ in terms of their morphological complexity and frequency distribution. In addition to two ERP experiments, one on participle inflection and one on plural inflection, we will report the results of two behavioral experiments on the same phenomena, adding off-line performance measures to the on-line ERP data. First, we will provide a brief description on how participles are formed in German and in our L2 learners' native language (Russian).

EXPERIMENT 1: PAST PARTICIPLES

Past participle formation in German involves two endings, *-n* appears on all participle forms of so-called strong (= irregular) verbs and *-t* appears on participle forms of all other verbs. Irregular verbs undergo (phonologically unpredictable) stem changes in the simple past (= preterit) and at times also in the participle (e.g., *laufen* [infinitive]–*gelaufen* [participle]–*lief* [simple past] ''to walk–walked–walked''). There are about 160 simplex verbs that fall into the strong (= irregular) class. Regular (= weak) verbs do not exhibit any stem changes in the past participle or the simple past (e.g., *tanzen–getanzt–tanzte* ''to dance–danced–danced''). In addition, traditional grammars identify a small class of 13 verbs of so-called mixed inflection, which take the (regular) participle ending *-t* but also show a stem change in the simple past and in the participle. Prefixation with *ge-* (as in *ge-tanzt*) is required when the verbal stem is stressed on the first syllable and is irrelevant for the morphological distinction between regular and irregular inflection, as it occurs for both regular (*-t*) and irregular (*-n*) participles. The participle suffix *-t* is applied under default circumstances in the sense of Marcus, Brinkmann, Clahsen, Wiese, and Pinker (1995), that is, to words for which lexical entries are not readily available, *-n* participle forms, by contrast, do not generalize to nonrhyming nonce words (Clahsen, 1997).

The Russian (perfective passive) participle endings are *-t*, *-n*, and *-on*, and the selection of one of these suffixes depends in part upon conjugation class and in part upon the phonology of the stem. Russian verbs fall into two conjugations. Verbs that fall into the first conjugation regular class, that is, those with stems in *-a*, always take *-n* (e.g., the participle form of *ubra-* ''clear up'' is *ubra-n*. Verbs of the second conjugation always take *-on* (e.g., *poxvalit* ~ *poxval-on* "praise–praised" participle). The effect of the phonology of the stem can be seen within first conjugation irregular verbs. For example, first conjugation stems ending in *-o* or *-u* take the participle suffix *-t* (*pobryznu-* ~ *pobryznu-t* "wash ~ washed"). First conjugation irregular verbs with consonant-final stems take *-on* in the participle (e.g., *unes- uneson* "carry off" [stem] ~ "carried off" [participle], and first conjugation verbs whose present stem ends in /j/ or have a nasal infix take *-t* in the participle. The system of participle formation in Russian is clearly different from the one in German in that, in Russian, the choice between the three endings is determined by conjugation class and by phonological segments at the right edge of verb stems. In German, however, the *-t* suffix is an overall default, whereas *-n* participle formation only applies to the subclass of strong verbs.

Experiment 1A: Elicited Production of Participles

This experiment was designed to determine the generalization properties of the two participle endings *-t* and *-n* in L2 German using a nonce-word production task that was previously employed with native speakers of German (Clahsen, 1997). Specifically, we ask whether the two endings show the same difference in generalizability in L2 learners as in native speakers of German (see Methods section). Table 1 shows the mean rates of expected participle suffixation given the simple past forms the L2 learners supplied.

A repeated measures analysis of variance (ANOVA) with suffix (*-t* vs. *-n*) as predicted by class (weak, strong, mixed) as dependent variable revealed a significant main effect [$F(3,48) = 17.47, p < .001$]. Pairwise comparisons between the four conditions in Table 1 (with an adjusted α level of .008) revealed significant differences for all comparisons except for "weak" versus "mixed" verbs. The L2 learners made use of *-t* participle suffixation, not only for mixed and weak verbs, but also for nonce verbs, for which they themselves produced strong simple past forms. By contrast, the *-n* participle ending was hardly ever applied to weak or mixed verbs. These results are similar to those reported in Clahsen (1997) for native speakers of German; *-t* was found to generalize widely to all kinds of nonce verbs, whereas extensions of *-n* participle formation were restricted to novel strong verbs. The present findings suggest that this contrast also holds for the group of L2 learners under study.

Table 1. Participles of Nonce Verbs

Form Supplied in Step 2	*Expected Participle Ending*	*Mean Rates of Expected Participle Endings in Step 3 (Maximum Score = 10)*	*SD*	*Range*
Strong past/ nonrhymes	*-n*	5.3	3.5	0–10
Strong past/ rhymes	*-n*	6.8	2.6	1–10
Weak past	*-t*	9.4	1.1	6–10
Mixed past	*-t*	9.1	1.1	6–10

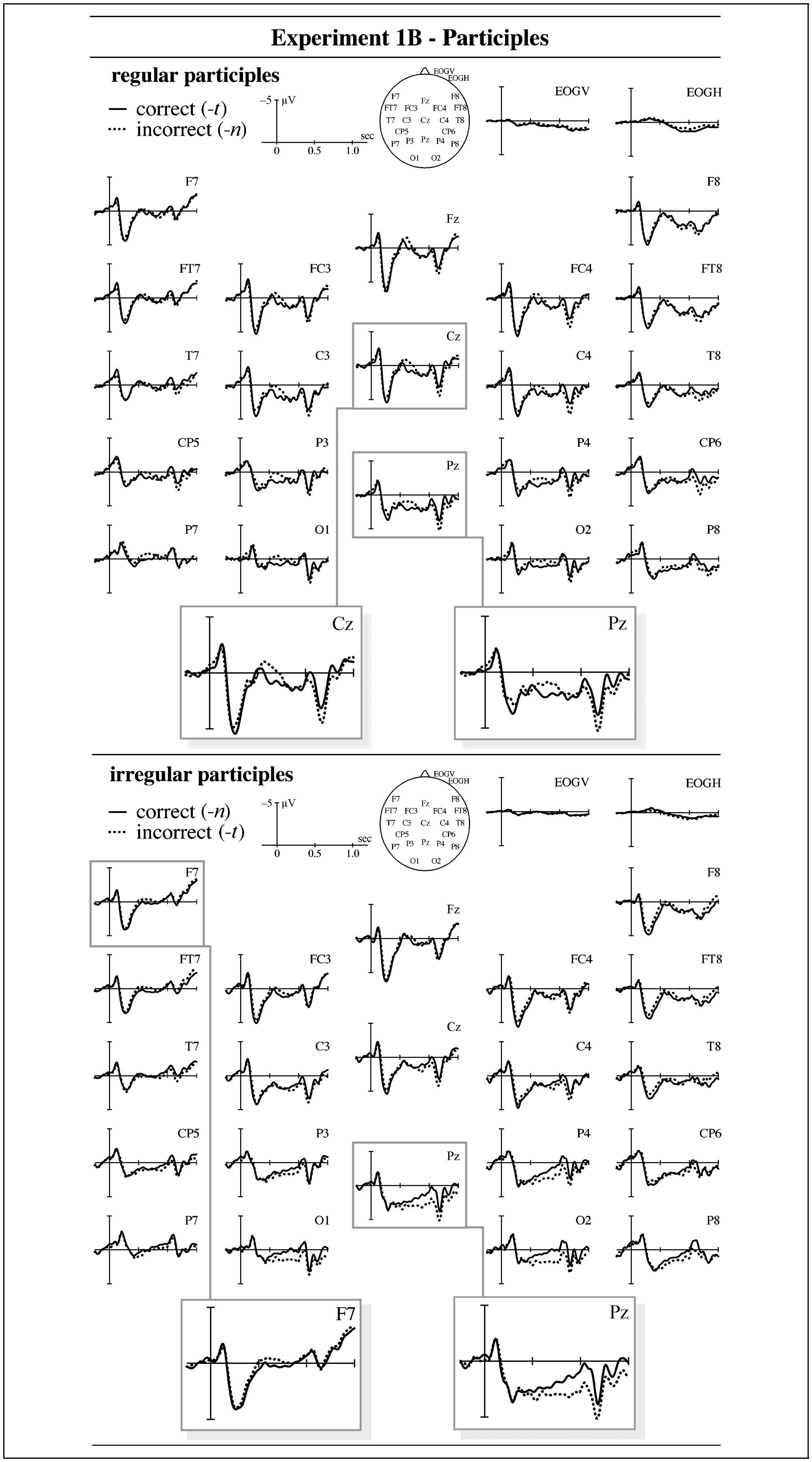
Experiment 1B: Event-related Brain Potentials to Participles

On-line morphological processing of participles was assessed by measuring ERPs in response to correctly or incorrectly inflected regular or irregular participles embedded in visually presented sentence contexts. Two sets of behavioral data were gathered in this experiment from the L2 learners: (a) elicited production of participle forms for the critical experimental items after the electroencephalography (EEG) session and (b) probe verification during the EEG sessions. Performance on both tasks was very good (>95% correct responses in the elicitation and >96% correct responses in the probe verification task), indicating that the participants actually read the stimuli to make the required distinction and that they were familiar with the critical verbs and their participle forms.

The ERP data of the L2 learners show a regular/irregular distinction. Regularizations (i.e., the regular *-t* suffixed to a strong verb such as *laufen* "run") elicited an anterior negativity between 250 and 600 msec as well as a small parietal positivity between 600 and 1000 msec compared with their correct counterparts. By contrast, irregularizations (i.e., *-n* suffixed to a weak verb such as *tanzen* "dance") yielded a centrally distributed negativity between 450 and 600 msec relative to the correct participle forms (see Figure 1).

With respect to the regularization condition, statistical analyses for the lateral electrodes in the early time window (250–600 msec) revealed a significant interaction of the factors Condition × Site [$F(2,34) = 8.75, p < .01$]. Subsequent analyses showed that there was a reliable effect of condition for the anterior [$F(1,17) = 5.71, p < .05$], but not for the central and posterior electrode positions. For the midline positions, there were no significant effects involving the factor Condition. Analyses in the late time window (600–1000 msec) for the lateral electrode positions revealed a reliable main effect of condition [$F(1,17) = 4.95, p < .05$] as well as a significant interaction of Condition × Site [$F(2,34) = 4.85, p < .05$] reflecting the fact that there was a reliable positivity over central [$F(1,17) = 4.45, p = .05$] and posterior [$F(1,17) = 7.53, p < .05$], but not over anterior sites. Analyses for midline positions demonstrated a main effect for condition [$F(1,17) = 4.47, p < .05$], which interacted with electrode [$F(2,32) = 3.74, p < .06$]. A significant positivity for regularizations was only observed for Pz [$F(1,17) = 7.11, p < .02$] and not for the other central electrode sites Cz and Fz. These statistical

Figure 1. Grand average ERPs (n = 18) for regular participles, correct *-t* versus incorrect *-n* forms (top), and for irregular participles, correct *-n* versus regularized (incorrect) *-t* forms (bottom).



analyses confirm the observed anterior negativity between 250 and 600 msec plus a later parietal positivity for regularized participle forms.

With respect to the irregularization condition, statistical analyses comprising the time window of 450–600 msec revealed a marginally significant main effect of condition for the midline electrodes [$F(1,17) = 3.57, p < .08$], which indicates a strong tendency toward a centrally distributed negativity for irregularizations.

These results show that the two types of morphological violation elicited different brain responses in the L2 learners. Although the anterior negativity had its maximum at left frontal sites in the L1 speakers, it was observed bilaterally in our L2 group. Note, however, that topographic variations of anterior negativities in this time range have been observed in a number of ERP studies with adult native speakers (see, e.g., Rodriguez-Fornells et al., 2001, for Catalan; Gross et al., 1998, for Italian; Weyerts, Penke, Münte, Heinze, & Clahsen, 2002, for German, who found either bilateral negativities or negativities restricted to right anterior sites). Both in terms of its timing and its distribution, the anterior negativity we found for the L2 learners falls within the range of variation that has been observed in studies with native speakers and can be taken to be an instance of a ''morphosyntactic negativity,'' an ERP waveform that is clearly different from the centro-parietal N400, which has been found to be associated with lexical–semantic processing (see, e.g., Osterhout, 1997). For inflectional morphology, anterior negativities for regularizations have been interpreted as reflecting violations of rule-based morphological processing (Rodriguez-Fornells et al., 2001; Penke et al., 1997; Weyerts et al., 1997). Given this interpretation, our results indicate that L2 learners are indeed employing regular rules of inflection in on-line morphological processing.

Regularizations also elicited a small parietal positive-going wave in the L2 learners with a latency of 600 to 1000 msec poststimulus, a waveform that can be identified as a P600. This effect may not have been seen in Penke et al.'s (1997) study of native speakers of German, which could be due a shorter analysis epoch of only 900 msec post stimulus onset (as opposed 1200 msec in the present study) or insufficient statistical power. In any case, a biphasic ERP pattern with an early anterior negativity followed by a P600 has been reported in a number of sentence processing studies (see, e.g., Friederici, 2002, for a review) as well as in studies examining morphological violations in Catalan (Rodriguez-Fornells et al., 2001) and German (Lück et al., 2001). The P600 has been interpreted to reflect controlled rather than automatized processing (Friederici, 2002; Hahne & Friederici, 1999), specifically reanalysis, repair, or effortful syntactic integration processes at the sentential level (Friederici, Steinhauer, & Pfeifer, 2002; Osterhout & Holcomb, 1992). Given that the P600 reflects sentence-level processes, the P600 we obtained suggests that in L2 learners, regularization errors not only affect early word-internal morphological processing (as indicated by the anterior negativity discussed above) but also later sentence-based processes. In other words, with respect to the *-t* regularization, two distinct processes could be identified, a relatively early process of automatic morphological decomposition and a later process that integrates the participle with the rest of the sentence.

EXPERIMENT 2: NOUN PLURALS

First, we will give a brief description of plural formation in German and Russian. German has a zero plural form and four overt plural suffixes [*-e*, *-er*, *-(e)n*, and *-s*], some of which can co-occur with an altered (umlauted) stem vowel. The use of the different plural allomorphs with specific nouns is arbitrary to varying degrees, and for most of them, there are preferred tendencies of plural formation interacting with the gender system and the phonological form of the singular form (see Marcus et al., 1995). In the main ERP experiment on noun plurals, we compared *-s* and *-n* plurals; the following remarks, therefore, focus on these two forms.

What is common to *-s* and *-n* plurals is that in contrast to the other plural forms, they do not involve any stem changes (''umlaut''). In other respects, however, they are very different from each other. First, among the five German plural allomorphs, *-n* is the most common with a type frequency of 48% and a token frequency of 45% in the CELEX lexical database (Sonnenstuhl & Huth, 2002), whereas *-s* is the least common plural form (type frequency, 4%; token frequency, 1.8%). Second, the form that acts most clearly as the regular default is the plural *-s*, despite its low frequency (see the work of Marcus et al., 1995). The *-s* plural is not restricted to a specific phonological environment and serves as the appropriate plural marking whenever a lexical entry is not readily available, that is, it generalizes to novel, unusual-sounding words and to rootless and headless nouns derived from other categories. None of these properties holds for *-n* plurals. Instead, there are particular morphophonological properties of nominal stems that favor *-n* plurals.

Russian makes use of a range of case–number morphemes and three declensional patterns for nouns including subdeclensions. Moreover, case–plural morphemes are largely vocalic and often stressed. Timberlake (1993) distinguishes among declension Ia, which is basically for masculine nouns; declension Ib, which is almost exclusively neuter; declension II, which is composed primarily of feminines; and declension III, which is characterized by the syncretic ending *-i* in genitive, dative, and locative, with further subdeclensions. Classes Ia, II, and IIIa prefer the nominative plural *-i*, whereas classes Ib and IIIb have a preference for the nominative plural *-a*. The preferred genitive plural is *-ov*/*-ev* in class Ia, *-ej* in class IIIa, and -∅ in the remaining classes. In addition, there is stem allomorphy in the plural for recognizable groups of nouns along with deviations from the preferred plural endings. Nationality terms, for example, use an otherwise unique nominative plural ending *-e*, borrowings as well as a substantial number of nouns have the nominative plural *-á* implying end stress throughout the plural (e.g., *inspéktor–inspektorá*). Clearly, noun plural formation in Russian is very different from German.

Experiment 2A: Acceptability Judgment of Noun Plurals

This experiment examines the generalization properties of the different German plural forms using a nonce-word plural judgment task that was previously employed with native speakers of German (Marcus et al., 1995). The L2 learners' mean ratings for the plural forms of rhyming and nonrhyming nonce nouns are shown in Table 2.

Table 2 shows that ratings for irregular plurals were overall higher than for the *-s* plural and that *-s* plural forms were judged as better for nonrhymes than for rhymes, whereas the opposite trend was seen for irregular plural forms. ANOVAs revealed a significant main effect of regularity [$F(1,17) = 13{,}60$, $p < .05$], no effect of rhyme, but rather a significant interaction of Rhyme × Regularity [$F(1,17) = 5.58$, $p < .05$]. The L2 learners' preference patterns for regulars and irregulars are parallel to those reported by Marcus et al. (1995) for native speakers of German, although the differences between conditions were smaller in the L2 learners. This might be because of the fact that the L2 learners have not yet completely mastered the German plural system, an issue to which we come back below.

Experiment 2B: Event-related Brain Potentials to Noun Plurals

To examine on-line morphological processing of noun plurals, we performed an ERP experiment with correct and incorrect plural forms embedded in auditorily presented sentences. Two sets of behavioral data were gathered in this experiment from the L2 learners, (a) elicited productions of plural forms for the critical experimental items after the EEG session, (b) probe verification during the EEG session. Performance on both tasks was good (>86% correct responses in the elicitation and >91% correct responses in the probe verification task), indicating that the participants carefully listened to the stimuli and were familiar with the critical nouns and their plural forms. It should be noted, however, that performance on these two tasks was worse than in the corresponding tasks for participles.

Visual inspection of the ERP data reveals a clear contrast between *-s* plural regularizations and irregularizations. Recall that the nouns tested in the "masculine" and "feminine" conditions require *-n* plurals in German and that in regularizations, the correct *-n* was replaced by *-s* (e.g., *Tube-n* vs. **Tube-s*). On the other hand, the nouns used in the "loan word" and the "name" conditions require *-s* in German, and in irregularizations, the correct *-s* was replaced by *-n*. The ERP data show that (*-s* plural) regularizations elicited a late positivity between approximately 850 and 1250 msec (see Figure 2). By contrast, misapplications of *-n* plurals to loan words yielded a centrally distributed negativity between 300 and 800 msec relative to the correct plural forms (see Figure 3). Finally, in the surname condition, correct and incorrect versions are seen to only differ slightly at parietal scalp sites, with incorrect items yielding a more negative waveform than the correct ones (Figure 3).

With respect to the masculine condition (see Figure 2), statistical analyses for the 850- to 1250-msec time window revealed a marginally significant main effect of condition [$F(1,17) = 3.37$, $p < .10$] and a reliable Condition × Hemisphere interaction [$F(1,17) = 4.55$, $p < .05$]. Subsequent analyses showed that regularized plurals of masculine nouns produced a significantly more positive waveform over the right hemisphere than the correct plural forms [left, $F(1,17) = 2.13$, $p < .17$; right, $F(1,17) = 4.37$, $p = .05$]. Analyses on midline positions revealed a reliable main effect of condition [$F(1,17) = 4.76$, $p < .05$]. To test for a possible anterior negativity, which had been observed in native speakers, an additional analysis was conducted on the data in Figure 2 (upper panel) for the time interval of 300–550 msec, which, however, did not reveal any significant effects for the factor Condition.

Regarding the feminine condition (Figure 2, lower panel), analyses for the 850- to 1250-msec time window revealed a significant Condition × Site interaction [$F(2,34) = 4.07$, $p < .05$] as well as a reliable three-way interaction of Condition × Hemisphere × Site [$F(2,34) = 5.22$, $p < .05$]. Regularized feminine nouns elicited significantly more positive waveforms than their correct counterparts over posterior electrode sites [left central, $F(1,17) = 3.61$, $p < .10$; left posterior, $F(1,17) = 5.22$, $p < .05$; right posterior, $F(1,17) = 5.03$, $p < .05$]. For midline positions, there was a significant Condition × Electrode interaction [$F(2,34) = 4.11$, $p < .05$]. Subsequent analyses showed a significant effect of condition at Pz

Table 2. Ratings of Plural Forms of Nonce Nouns

	Mean Ratings	*SD*	*Range*
Highest rated irregular plural/rhymes	4.5	0.35	3.8–5
Highest rated irregular plural/nonrhymes	4.4	0.37	3.8–5
-s plural/rhymes	3.5	0.91	1.3–4.8
-s plural/nonrhymes	3.6	0.88	1.9–5

Figure 2. Grand average ERPs (n = 18) for masculine nouns, correct *-n* versus regularized (incorrect) *-s* forms (top), and for feminine nouns, correct *-n* versus regularized (incorrect) *-s* forms (bottom).

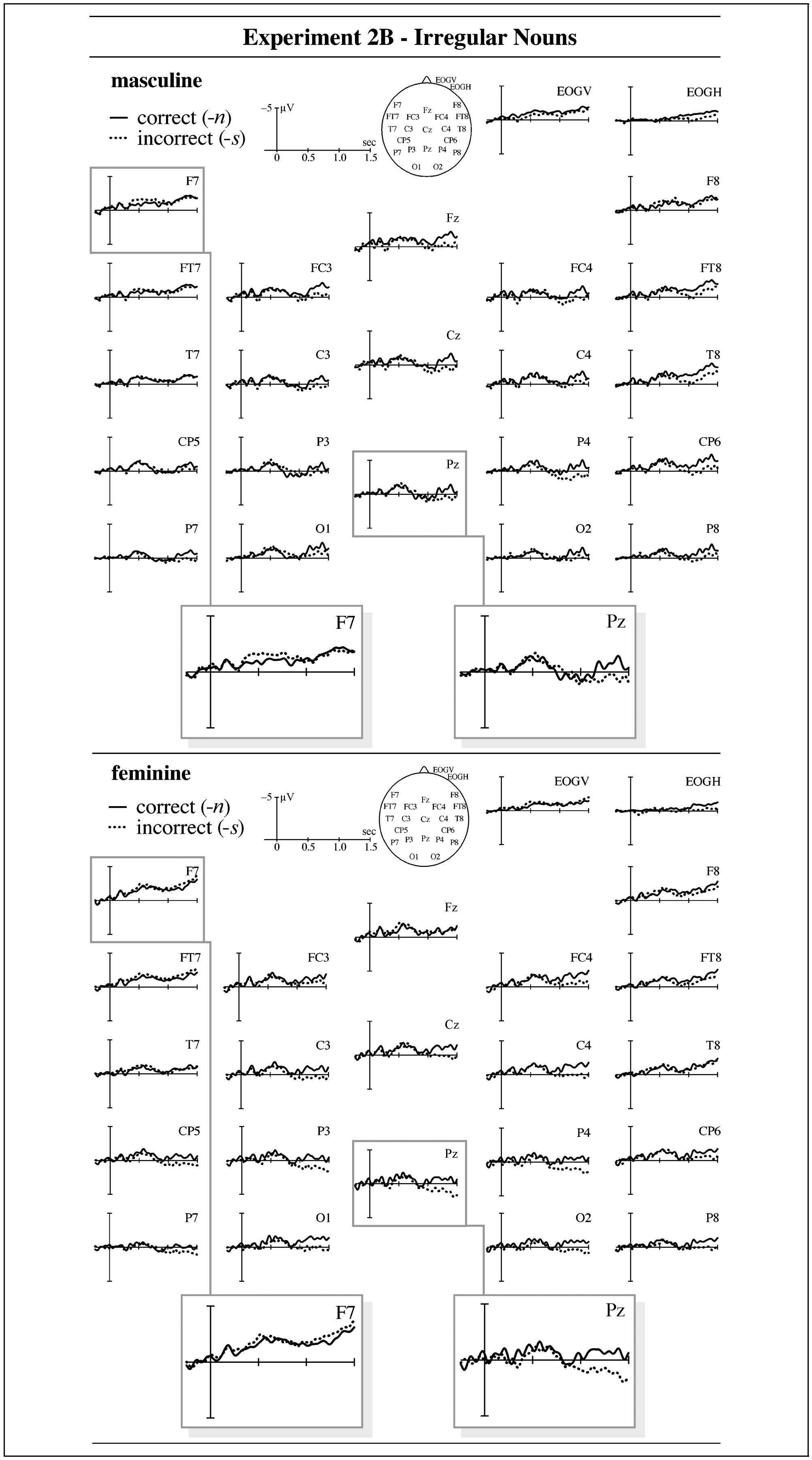
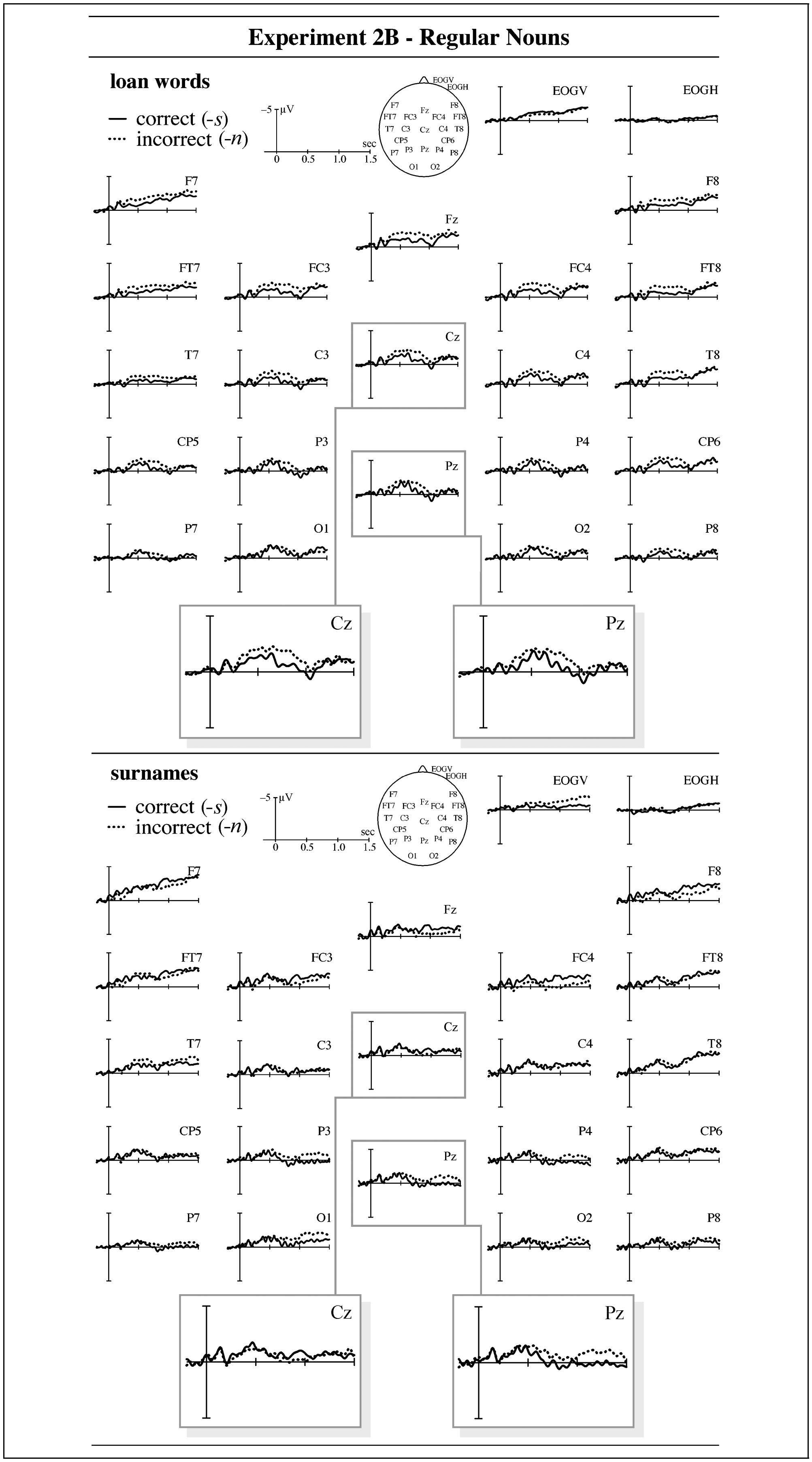


Figure 3. Grand average ERPs (n = 18) for loan words: correct *-s* versus incorrect *-n* forms (top), and for surnames, correct *-s* versus incorrect *-n* forms (bottom).



[$F(1,17) = 4.41$, $p = .05$]. Again, as for the masculine condition, an additional analysis for the time window of 300–550 msec did not reveal any reliable effects of condition; hence, there were no signs of an anterior negativity.

Concerning irregularizations (see Figure 3), analyses in the 300- to 800-msec time window revealed a highly significant main effect of condition for lateral [$F(1,17) = 9.41$, $p < .01$] and midline electrodes [$F(1,17) = 8.29$, $p < .01$], which did not interact with any topographical variables. This confirms the centrally distributed negativity for irregularizations seen in Figure 3 (upper panel).

With respect to the surname condition, visual inspection of Figure 3 suggested a more negative waveform between 500 and 900 msec as well as between 900 and 1500 msec over posterior positions. ANOVAs for the 500- to 900-msec time window revealed a marginally significant interaction of Condition × Site [$F(2,34) = 3.03$, $p < .10$] for lateral electrodes and a significant interaction of Condition × Electrode [$F(2,34) = 3.90$, $p < .05$] for midline electrodes. Subsequent analyses showed a reliable effect of condition in the posterior region [$F(1,17) = 5.82$, $p < .05$] and at Pz [$F(1,17) = 5.88$, $p < .05$]. For the later time window (900–1500 msec), there was a marginally significant interaction of Condition × Site [$F(2,34) = 4.16$, $p < .06$]. However, when analyses were calculated for each site separately, only the posterior region revealed a marginally significant effect of condition [$F(1,17) = 3.13$, $p < .10$]. There was also a significant interaction of Condition × Electrode for the midline positions [$F(2,34) = 5.72$, $p < .05$], which gave rise to a reliable condition effect at Pz [$F(1,17) = 4.49$, $p < .05$].

These results show that the two kinds of morphological violation elicited different brain responses in our L2 learners. Regularizations elicited a late positivity, an ERP component that, in terms of its timing and distribution, can be identified as a P600. Irregularizations, on the other hand, yielded an N400-like waveform, that is, a centrally distributed negativity between 300 and 800 msec. This effect was stronger in the loan word condition than for surnames, and in the surname condition, it occurred relatively late (after 500 msec) and had a more parietal distribution. Crucially, however, the negativity found for irregularizations represents a clearly different ERP component from the late positivity (P600) that was seen for *-s* plural regularizations of both feminine and masculine nouns.

The central negativity for irregularizations has also been found for native speakers of German in both the visual and the auditory ERP studies (Lück et al., 2001; Weyerts et al., 1997) and has been argued to reflect a pseudoword effect. Indeed, from a linguistic perspective, misapplications of *-n* plurals to nouns that take *-s* plurals in German produce items that are similar to pseudowords (e.g., **Waggonen* ''wagons''), whereas correct regulars (*Waggon-s*) are existing (morphologically complex) words. The central negativity we found for irregularizations corresponds to this difference, and it resembles the N400 effect seen in many previous studies for pronounceable pseudowords (Rugg, 1987).

We interpret the late positivity (P600) as resulting from the L2 learners' recognition of a morphosyntactic violation. Hence, it occurs with misapplications of the *-s* pluralization rule, but not with misapplications of irregular patterns. This effect was also seen in Lück et al.'s (2001) study of native speakers of German. Note, however, that an additional left anterior negativity was found to precede the P600 in the L1 speakers. It is conceivable that an *-s* plural regularization error is initially subject to (possibly automatic) processes of morphological parsing by which the inflected word is decomposed into its constituent morphemes; the anterior negativity could reflect the combinatory violation detected at this level. At a later stage of processing, the regularized plural form has to be integrated with the rest of the sentence, and the P600 effect that Lück et al. found for L1 German speakers suggests that regularization errors cause additional processing at this level, perhaps because participants try to repair or reanalyze the regularized plural form before integrating it with the rest of the sentence. Given this account of the biphasic ERP pattern in native speakers, our present findings indicate that the L2 learners do not employ early processes of word-internal morphological decomposition to parse a plural regularization error, hence, the lack of an anterior negativity, but employ repair and integration processes at a later stage of processing, as indicated by the P600.

GENERAL DISCUSSION

The most salient and consistent result of the present study is that adult L2 learners respond differently to violations of regular and irregular inflection during online morphological processing. For misapplications of regular rules of inflection, they showed ERP effects that have independently been argued to tap morphosyntactic processing, namely an anterior negativity and/or a P600, whereas misapplications of irregular inflection revealed an ERP effect (the N400) that has been claimed to be characteristic of lexical processing and interpretation.

From the perspective of dual-mechanism models of inflection, a *-t* participle affix appearing on an irregular verb or an *-s* plural incorrectly affixed to an existing noun are combinatorial violations that represent misapplications of a default rule to a verb or a noun that would normally block the rule. By contrast, irregular inflection is based on full-form storage, and misapplications of irregular inflection produce pseudowords. The brain responses seen in L2 learners for the two kinds of morphological violation, that is, ''morphosyntactic'' ERP components for combinatory violations and a lexical N400 for misapplications of irregular patterns, are compatible with this distinction and suggest that the two processing routes posited by dual-mechanism models of inflection (lexical storage and morphological decomposition) are also accessible and employed by L2 learners. This finding does not support Ullman's (2001) original claim that L2 processing is ''largely dependent upon declarative/lexical memory'' (p. 105) according to which one would expect to find the same ERP responses in L2 learners for regular inflectional processes as for irregular inflection. Instead, our ERP results indicate that different processes are involved in regular and irregular inflection. More recently, however, Ullman (2004) suggested that high proficiency levels in L2 learners can lead to enhanced reliance on the procedural processing system. The differences we found in the L2 learners' ERP responses for participles and plurals are indeed compatible with this suggestion as the degree of automaticity appears to be lower for the system, which is more difficult for the L2 learners. Recall that in native speakers of German, a left anterior negativity was found in three different experiments on participles (Penke et al., 1997) and in both the visual and the auditory ERP studies on noun plurals (Lück et al., 2001; Weyerts et al., 1997). In the L2 learners, an anterior negativity was found for participles, but not for noun plurals. One possibility would be that the working-memory demands incurred by the task assigned to the participants in the two ERP experiments (to verify a probe sentence) were higher for L2 learners than for native speakers, but this only provides a partial account of the ERP results. The probe verification task was given in both the participle and the plural experiment yielding similar task demands, and yet the results were different. The L2 learners performed similarly to native speakers for participles, but not for plurals. We therefore do not think that the absence of an anterior negativity in the L2 learners' ERPs to plural violations can be explained in terms of working-memory limitations.[1]

Instead, we suggest that the L2 learners employ early automatic processes of word-internal morphological decomposition for participles (as reflected by the anterior negativity), but not for plurals, and this contrast in the ERP results coincides with different levels of proficiency for participles and plurals. The German noun plural system is rather unusual in that it has a default rule (the plural *-s*) with an extremely low frequency, which means that more than 95% of the German nouns form their plurals according to one of the various irregular patterns. The participle formation system has a more common frequency distribution (in that irregular verbs do not outnumber regular ones) and a relatively small number of irregular patterns. Moreover, the plural system is linguistically more diverse in that it comprises five different endings, whereas participle formation only involves the choice between *-t* and *-n*. These factors make it easier for L2 learners to acquire German participle formation in nativelike ways than to learn the noun plural system of German. There are indications for that in the behavioral data, as the elicited productions on the critical items used in the two ERP experiments yielded considerably worse correctness scores for plurals than for participles. Clearly, plural formation in our L2 participants is less stable than participle formation. Correspondingly, the ERP results suggest that the L2 learners' processing of participles is more automatized and nativelike than of noun plurals.

Our results are also compatible with previous ERP studies on L2 processing. Studies investigating lexical–semantic processing in L2 learners and bilinguals obtained N400 effects for semantic anomalies (Hahne, 2001; Hahne & Friederici, 2001; Weber-Fox & Neville, 1996, Ardal, Donald, Meuter, Muldrew, & Luce, 1990) and pronounceable nonwords (McLaughlin, 1999) in nonnative speakers, which were similar to those found in studies with L1 speakers. Previous ERP studies of syntactic processing in nonnative speakers demonstrated P600 effects for phrase-structure violations (Hahne, 2001; Weber-Fox & Neville, 1996) and violations of subject–verb agreement and gender concord (Sabourin, 2003). The learners' proficiency in the L2 seems to affect the ERP findings. Hahne (2001) found a P600 effect for a group of highly proficient Russian learners of German, but when Hahne and Friederici (2001) administered the same experiment to a group of Japanese L2 learners with a lower proficiency in German, there were no significant differences between the correct sentences and the phrase-structure violations in any relevant time window. Likewise, Friederici et al. (2002) report findings from an artificial grammar experiment in which adult subjects were trained on an artificial language system (BROCANTO) to a level at which they were highly proficient and produced hardly any errors. A subsequent ERP experiment examining syntactic violations in BROCANTO revealed the familiar biphasic ERP pattern known from comparable studies of natural languages in native speakers, that is, an early negativity followed by a P600. Finally, Sabourin (2003) found a P600 for gender concord violations, but only in the subgroup of German L2 learners of Dutch, who Sabourin independently demonstrated to be more proficient in L2 gender marking than the other subgroups of L2 learners she tested. Taken together, these results suggest that at least in domains in which they are highly proficient, L2 learners can employ the same processing mechanisms as L1 speakers.

Conclusion

The results of the present study show regular/irregular contrasts in adult L2 learners' processing of inflected words. In processing combinatory violations, the L2 learners evidenced ERP components (an anterior negativity and/or a P600) that have been linked to morphosyntactic processing, and for misapplications of irregular inflection, they showed an ERP effect (the N400) that has been claimed to be characteristic of lexical processing. These results are consistent with the two processing routes posited by dual-mechanism models of inflection (lexical storage and morphological decomposition) and suggest that they are also accessible in L2 processing of inflected words. The similarities of the electrophysiological responses of the L2 speakers to those previously observed in native speakers provide evidence for largely shared processing mechanisms in L1 and L2 inflectional morphology.

METHODS

Eighteen learners of German with Russian as L1 were tested (mean age 25 years, range 20–33; 5 men). They had lived in Germany for an average of 4.5 years (range 0.5–12 years) and had their first exposure to German at age 17 years (range 8–29). One of the participants reported that he had first been exposed to German at about the age of 8 years, but like the others, he did not consider himself bilingual. All participants were right-handed. They had no known hearing deficits and were paid for their participation. When the experiments took place, all learners were living and working in the Leipzig area. All the participants reported using German on a daily basis for interaction with native and nonnative speakers, that is, all participants use German in their work environment, and all of them have German friends or partners, and they communicate with them in German. To obtain a general measure of their proficiency, they were asked to rate their German language proficiency on a 6-point scale[2] (6 = *very good*, 1 = *hardly any knowledge*); this yielded a relatively high average score of 5.0.

All the L2 learners participated in an elicited participle production task (Experiment 1A), a plural acceptability judgment task (Experiment 2A), and in the two ERP experiments, one on participles (Experiment 1B) and one on plurals (Experiment 2B). Experiment 2B was conducted in the same session as Experiment 2A. The two ERP experiments were separated by at least one week, and the order in which the experiments were administered was counterbalanced across participants.

Experiment 1A employs the elicitation task from Clahsen (1997), in which participants were presented with a nonce verb in the infinitive and first-person simple past form (Step 1). They were then asked to repeat the simple past form of the nonce verb (Step 2), and finally they had to produce the participle form, that is, an inflectional form of the nonce word that they had not seen before (Step 3). All nonce verbs were presented as part of sentences in written form and in a pseudorandomized order. Participants were asked to carefully read the sentences and to fill in blanks for the various verb forms. There were 10 sentences each in four experimental conditions: (a) regular (''weak'') nonce verbs, (b) nonce verbs with a mixed inflectional pattern, (c) irregular (''strong'') nonce verbs that rhymed with existing ones, (d) nonrhyming irregular nonce verbs. The simple past forms provided an unambiguous cue as to whether a nonce verb was regular (in which case, the simple past form had a *-te* suffix and no stem changes), ''mixed'' (simple past forms with *-te* and vowel changes) or irregular (simple past forms with vowel changes and no *-te*). One participant had to be excluded from the analysis because of a high error rate of more than 90% in Step 2. All other participants carried out Step 2 virtually perfectly. There were three trials (0.4%) in which an error occurred in Step 2, and these were excluded from any further analysis.

Experiment 1B adopts the design and materials of the ''sentence'' experiment from Penke et al. (1997) excluding, however, the additional nonce verb condition. Our version has a 2 × 2 design: participle forms were suffixed with *-t* (= regular) or with *-n* (= irregular) and were correct or incorrect. Two types of violations were tested: regularizations, a regular *-t* suffixed to a verb that requires an irregular form (**gelauft* vs. *gelaufen* ''run'' past participle), and irregularizations, a regular (''weak'') verb incorrectly suffixed with *-n* (**getanzen* vs. *getanzt* ''danced'' participle). All the strong verbs tested were of the so-called A–B–A class, which have stem changes in the simple past, but not in their participle forms. Hence, the participle forms we tested only differed in terms of their endings, *-t* versus *-n*. There were 50 regular and 50 irregular participles, which were matched for participle and lemma frequencies. These critical participles were embedded in simple declarative sentences, which all consisted of six words. The participle was the final word of the sentence (see Penke et al., 1997, for further details). Sentences were distributed in two blocks such that a correct and an incorrect version of a given participle occurred in different lists. The two blocks were pseudorandomized with the general constraints that there were less than four consecutive trials containing either regular or irregular participles and less than four consecutive trials containing either correct or incorrect participle forms. Three different combinations of presentation order of the two blocks were created. Three more presentation lists were generated by reversing the order of the original lists. Each of these six lists was presented with a probe verification task (see below), which required a button press either with the left or with the right hand, thus yielding a total number of 12 different lists. None of the lists was presented more than twice.

Participants were tested in a soundproof booth. Sentences were presented on a computer screen word by word in yellow letters on a blue background. The words were presented for 700 msec with no blank interval in between.[3] The stimulus onset asynchrony was as in Penke et al. (1997) with a 2300-msec interval between two stimulus sentences. The words subtended 0.75° of visual angle in height and a maximum of 4.85° in width.

After 10 sentences, a ''probe sentence'' was presented in red letters. Half of these probe sentences were exact repetitions of one of the 10 sentences shown before and the other half differed with regard to the content words of any of the previous sentences.[4] True and incorrect probes were equally distributed across the four experimental conditions. Participants received a written instruction in which they were asked to carefully read each sentence and to indicate via a push-button response whether a probe sentence was a repetition of one of the previous 10 sentences. Furthermore, they were asked to minimize eye and body movements during the presentation of the sentences. The experiment was subdivided in four blocks of 55 sentences each. Subsequent to the EEG session, a list of all critical verbs was read out to the participants in their infinitive form and they were asked to generate the participle forms.

The EEG was recorded from 25 scalp sites (Sharbrough, 1991) by means of Ag/AgCl electrodes attached to an elastic cap: FP1/2, F7/8, F3/4, FT7/8, FC3/4, T7/8, C3/4, CP5/6, P7/8, P3/4, O1/2, Fz, Cz, and Pz. Recordings were referenced to the left mastoid. To control for eye movement artifacts, the horizontal electrooculogram (EOG) was monitored from electrodes at the outer canthus of each eye and the vertical EOG from two electrodes located above and below the participant's right eye. Electrode impedances were kept below 5 kΩ. EEG and EOG channels were recorded continuously with a band pass from DC to 40 Hz with a digitization rate of 250 Hz. ERPs were filtered off-line with 10 Hz low pass for the plots, but all statistical analyses were computed on nonfiltered data. ERPs on the critical participle forms were recorded for 1200 msec separately for each participant, electrode, and condition. All ERP averages were aligned to a 200-msec baseline before the onset of the critical word. Trials with ocular or amplifier saturation artifacts were excluded from the averages. The average percentage of rejected trials was 16%. All statistical analyses were performed on the mean ERP amplitudes. Based on visual inspection and previous studies, we chose three different time windows: 250–600 msec for the anterior negativity, 600–1000 msec for the late positivity, and 450–600 msec for possible N400 effects. Repeated measure ANOVAs were performed on all lateral electrodes with three within-subject variables: condition (correct vs. incorrect), hemisphere (left vs. right), and site (anterior vs. central vs. posterior). The variables hemisphere and site were completely crossed, yielding six regions-of-interest with three electrodes each: left anterior (F7, FT7, and FC3), right anterior (F8, FT8, and FC4), left central (T7, C3, and CP5), right central (T8, C4, and CP6), left posterior (P7, P3, and O1), and right posterior (P8, P4, and O2). The Greenhouse–Geisser correction was applied whenever effects with more than one degree of freedom in the numerator were evaluated. Below, we report uncorrected degrees of freedom and corrected probabilities.

Experiment 2A employs the paper-and-pencil judgment task from Marcus et al. (1995), in which participants are asked to judge the acceptability of plural forms of nonce nouns, 12 monosyllabic items that rhymed with existing German nouns that take irregular plural forms (e.g., *Pund* on analogy with *Hund–Hunde* ''dog–dogs'') and 12 nonrhymes. Each item was first presented in a context sentence in its singular form in masculine or feminine gender, followed by 8 test sentences each containing one of the plural forms of German. Participants were asked to rate each test sentence on a 5-point scale (1 = *perfectly natural*, 5 = *very unnatural*) for acceptability. The gender of the items was counterbalanced across participants as was the sequential order in which the plural forms were presented. Thus, four different experimental versions were presented. The experimental items were presented in a pseudorandomized order such that there were no more than three rhyme or nonrhyme items in direct succession. In the analysis, each rating was subtracted from 6, so that the higher the score, the more natural a given plural form. Following Marcus et al., we took the highest rated irregular for comparison with the ratings of the regular *-s* plural. A two-way ANOVA with Regularity (*-s* plurals vs. irregular plurals) and Rhyme (rhyming vs. nonrhyming nouns) as within-subjects factors was conducted on the mean rating scores.

Experiment 2B adopts the design and materials of the auditory ERP violation experiment from Lück et al. (2001), in which the critical items were matched for the same frequency and morphophonological criteria as detailed by Weyerts et al. (1997). There were 48 critical nouns forming their plural with *-(e)n*, 24 masculine/neuter and 24 feminine nouns; the latter were disyllabic and ended in a schwa. Another 48 critical nouns required *-s* plurals, none of which had a stem-final vowel, most of which were loan words. In addition, 24 surnames served as critical items in the ''surname condition,'' all of which require *-s* plurals in German. Each noun was presented twice, in its correct plural form and with an incorrect plural form. Two types of violation were tested: regularizations, a regular *-s* suffixed to a noun that requires an *-n* plural form (**Vases* vs. *Vasen* ''vases''), and irregularizations, nouns that require *-s* plurals incorrectly suffixed with *-n* (**Waggonen* vs. *Waggons* ''wagons''). The critical words were embedded in sentences and always appeared in direct object position followed by an adverbial or a prepositional phrase. Four different experimental sentences were constructed for each noun, and each of these 480 sentences was recorded in two versions, once with the correct and once with the incorrect plural form of the critical noun. The different experimental sentences were counterbalanced across subgroups of participants, and each participant received 480 sentences. The order of presentation was pseudorandomized such that no more than three consecutive items belonged to the same condition or contained either only correct or incorrect plural forms, and repetitions of the same noun were separated by at least 27 intervening sentences. Sentences were spoken by a trained female speaker of German and digitized at a sampling rate of 44 kHz. Participants were seated in a comfortable chair in a soundproof booth 130 cm in front of a computer monitor. Sentences were presented via loudspeaker while a fixation signal appeared on the screen. Trials were separated by an intertrial interval of 2500 msec. After eight sentences, participants listened to a warning tone followed by a ''probe sentence'' while a question mark appeared on the screen, and participants were instructed to give a push-button response indicating whether this sentence had been presented as one of the previous eight trials. Half of these probe sentences were exact repetitions of one of the eight sentences shown before, and the other half differed with regard to the content words of any of the previous sentences. Participants were given a visual feedback on their responses. After every 48 sentences, participants were given a short break.

The procedures for ERP recording and data analysis were as described for Experiment 1B. In the present experiment, ERPs on the critical nouns were computed for 1500 msec relative to word onset separately for each participant, electrode, and condition. Trials with ocular or amplifier saturation artifacts were excluded from the averages, with an average of 18% rejected trials. Subsequent to the EEG session, all critical nouns were read out to the participants in their singular form, and they were asked to generate the corresponding plural forms.

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Notes

1. Moreover, anterior negativities have been argued to increase with working-memory demands (Felser, Münte, & Clahsen, 2003). Thus, if the task we assigned to participants affected the L2 learners' working memory more than the native speakers, we should have seen more pronounced anterior negativities in the L2 learners than in the native speakers, the opposite of what we found. For these reasons, the pattern of results is unlikely to be due to the task assigned to participants.

2. Self-ratings have been used in many previous L2 processing studies as an index of general language proficiency (see e.g., Dussias, 2003; Sabourin, 2003; Frenck-Mestre, 2002), and self-rating scores have been shown to correlate with other proficiency measures (Fernández, 2002).

3. This procedure deviates slightly from Penke et al. (1997) where words were shown for 300 msec, followed by a blank screen for 400 msec. For the present study, we chose longer presentation times, as word recognition processes are likely to be slower in L2 learners than in native speakers.

4. Note that we created new incorrect probe sentences, as the ones used by Penke et al. (1997) included only very slight modifications of the correct sentences, which we thought were too hard for the L2 learners to detect.

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