BRIEF REPORT

Syntactic anomaly elicits a lexico-semantic (N400) ERP effect in the second language but not the first

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Abstract

Recent brain potential research into first versus second language (L1 vs. L2) processing revealed striking responses to morphosyntactic features absent in the mother tongue. The aim of the present study was to establish whether the presence of comparable morphosyntactic features in L1 leads to more similar electrophysiological L1 and L2 profiles. ERPs were acquired while German–English bilinguals and native speakers of English read sentences. Some sentences were meaningful and well formed, whereas others contained morphosyntactic or semantic violations in the final word. In addition to the expected P600 component, morphosyntactic violations in L2 but not L1 led to an enhanced N400. This effect may suggest either that resolution of morphosyntactic anomalies in L2 relies on the lexico-semantic system or that the weaker/slower morphological mechanisms in L2 lead to greater sentence wrap-up difficulties known to result in N400 enhancement.

Descriptors: Bilingualism, ERP, Syntactic violations, N400

The sensitivity of event-related brain potentials (ERPs) to syntactic and semantic processes in the native language (L1) makes them appealing for examining the second language (L2). In L1, manipulations of semantic expectancy invariably elicit the N400 component (Kutas & Hillyard, 1984), whereas syntactic violations elicit two kinds of components: (typically left-lateralized) anterior negativities (LAN; Münte, Heinze, & Mangun, 1993), and the P600 component, or Syntactic Positive Shift (Hagoort, Brown, & Groothusen, 1993; Osterhout & Holcomb, 1992). In L2, semantic anomalies often elicit slightly delayed (Ardal, Donald, Meuter, Muldrew, & Luce, 1990; Hahne, 2001; Ojima, Nakata, & Kakigi, 2005; Weber-Fox & Neville, 1996) and reduced (Hahne, 2001) N400 components, effects attributable to age of exposure and proficiency (Moreno & Kutas, 2005). In contrast, ERP studies of syntactic violations have reported more striking, but also more variable, L1–L2 differences. For instance, the issue of whether the LAN is absent in L2 when acquired after the age of 3 (Weber-Fox & Neville, 1996) and whether this is independent of L2 proficiency (Hahne, 2001; Hahne & Friederici, 2001) was recently reopened by reports of LANs being elicited only in high- (but not low-) proficiency L2 speakers (Rossi, Gugler, Friederici, & Hahne, 2006), or only for the morphological feature, in which L2 learners were more proficient

(violations of German participles but not plurals; Hahne, Müller, & Clahsen, 2006).

The present study is concerned with the role of the similarity of the morphosyntactic structures of L1 and L2, with relevant evidence relating to the P600 component. P600 has been reported to be delayed in L2 in high-proficiency speakers (Hahne, 2001), with early-to-intermediate age of acquisition (Weber-Fox & Neville, 1996), and reduced and delayed (Rossi et al., 2006) or altogether absent (Hahne & Friederici, 2001) in lower-proficiency speakers, particularly when L2 acquisition was late (>16 years, Weber-Fox & Neville, 1996). Importantly, in studies that failed to detect a P600 in L2, L2 was morphosyntactically more dissimilar from the mother tongue (Hahne & Friederici, 2001) than in studies that did report it (Rossi et al., 2006), raising the intriguing possibility that L1 shapes the sensitivity to the morpho-syntax of L2. Further evidence came from a recent study by Ojima et al. (2005) on subject–verb agreement violations (*Buses stops here*), which found no P600 either in low- or high-proficiency L2 speakers. The authors commented that the lack of a P600 in L2 could be due to the absence in L1 (Japanese) of the morphological features that support subject–verb agreement in L2 (English). By implication, violations of morphosyntactic features present in both L1 and L2 can be expected to elicit comparable P600 effects in the two languages because morphological segmentation processes may generalize from L1 to L2. We test this conjecture by examining morphosyntactic violations involving verb inflections in German (L1) and English (L2) in a visual presentation paradigm similar to that used by Ojima et al. (2005).

We also address an important methodological concern regarding the ERP L2 sentence-processing literature: It has been largely reliant on between-subjects comparisons (L2 group vs. L1 group). Since ERP correlates of syntactic violations are subject to considerable interindividual variability, L1 versus L2 ERP differences could reflect such variability, rather than or as well as genuine L1 versus L2 differences. When the examined syntactic features of L1 and L2 are comparable, the desideratum of within-subjects L1 versus L2 comparisons can be achieved (as it has been in studies of word recognition in L2; cf. Phillips, Segalowitz, O'Brien, & Yamasaki, 2004).

Method

Participants

Eighteen German–English highly proficient bilinguals (13 women, mean age 28.11 years, range 19–46 years, $SD = 8.49$), with English as the first foreign language acquired at school (mean onset age of 10.17 years, range 6–12 years, $SD = 1.62$), and 18 native speakers of English (9 women; mean age 22.78 years, range 20–31 years, $SD = 3.68$), all of whom lived in a monolingual environment and were not fluent in another language, participated in the study after providing informed consent. The procedure was approved by the School of Psychology (Exeter University) ethics committee. All participants were right-handed (Chapman & Chapman, 1987). Only German participants with perfect or good reading and understanding in the self-assessed English proficiency questionnaire (on a *perfect*, *good*, *sufficient*, and *poor* scale) were tested; they had lived in the United Kingdom for an average of 4.64 years (range 0.5–12 years, $SD = 3.96$). Ten German participants rated their understanding of English as perfect and 8 as good; 9 rated reading as perfect and 9 as good. In speaking and writing, 7 rated their ability as perfect, 10 as good, and 1 as sufficient. Eight German participants felt more comfortable using German, 2 felt more comfortable with English, and the remaining 8 felt equally competent in both languages.

Stimuli and Procedure

The stimuli (see Figure 1) were German and English five-word sentences. Some sentences were plausible and grammatically correct, whereas others contained a morphosyntactic (verb morphology) violation or a semantic violation in the final word. Each final word and sentence body occurred equally often in each of the three conditions over participants. The testing, preceded by 30 practice sentences (with feedback), consisted of 80 sentences from each condition (correct, semantic, syntactic) presented visually in random order without feedback. A sentence was to be judged acceptable if it was "well formed" and if it "made sense." The assignment of left and right hand key presses to "acceptable" and "unacceptable" responses and the order of testing in the two languages in the German group were counterbalanced across participants.

ERPs

The EEG was acquired (sampling rate 500 Hz, bandpass 0.016–100 Hz, reference Cz, ground AFz) using BrainAmpMR amplifiers (Brain Products, Munich, Germany) and Ag/AgCl-electrode caps (ElectroCap International Inc., Eaton, Ohio). Fifty-eight electrodes were placed on the scalp in a 10-10

configuration, two on the outer canthi of the eyes, two supra- and infraorbitally, and two on the earlobes. Off-line, the EEG was lowpass filtered (40 Hz, 24 dB/oct), subjected to regression-based ocular artifact correction, and segmented into 900-ms-long ERP epochs time-locked to the onset of the critical (final) word in every sentence associated with a correct response plus 100 ms baseline preceding the critical word. Individual epochs were inspected for residual ocular and other artifacts.

For objective, data-driven, segmentation of ERPs into components for subsequent analyses, ERPs were first subjected to a temporal varimax-rotated principal components analysis (PCA; Donchin & Heffley, 1978) on the covariance matrices, with 450 time points (0–900 ms) as variables and 9396 cases (18 subjects × 3 violations + 18 subjects × 2 languages × 3 violations) and eigenvalue ≥ 1 as the component extraction criterion. Before PCA, ERPs were re-referenced to the average reference, which is optimal in such correlational approaches. Linked-ears-referenced ERP waveforms and topographies of experimental effects are presented for comparisons with other studies; average-referenced topographies are also presented in order to compare them to topographies of PCA components. The scores of PCA components, which explained $\geq 1\%$ of variance and had high loadings (amplitude) in the 200–900-ms interval, were submitted to an analysis of variance (ANOVA) after being averaged for five scalp regions on the left: anterior frontal (FP1, AF3, F1, F3, F5, F7), posterior frontal (FC1, FC3, FC5, C1, C3, C5), temporal (T7, TP7, CP5, P7), parietal (CP1, CP3, P1, P3, P5), and parietal-occipital (PO1, PO3, PO7, O1), and the corresponding regions on the right, excluding midline electrodes. Significance levels were Huynh–Feldt corrected for violations of sphericity, but unadjusted degrees of freedom are reported.

Results

Behavioral Results

A Violation × Language (L1, L2) ANOVA on acceptability judgment accuracy of German participants revealed reliable main effects of Violation and Language as well as a reliable interaction of these two factors, $F(2,34) = 14.82$, $p < .001$; $F(1,17) = 17.42$, $p < .01$; $F(2,34) = 11.16$, $p = .001$, respectively. The ANOVA comparing the two subject groups, with the factors Violation and Group, found only a reliable effect of Violation, $F(2,68) = 37.39$, $p < .001$. Judgment accuracy was higher for the syntactically anomalous sentences (English group: 96%; German group: L1, 93%; L2, 91%) than for the correct (English group: 82%; German group: L1, 84%; L2, 74%) and semantically anomalous (English group: 71%; German group: L1, 86%; L2, 69%) sentences.

ERP Results

Four principal components (PCs) were found between 200 and 900 ms (see Figure 2, right). Three of them were modulated by violation type as revealed by ANOVAs with factors Violation (3 or 2), Region (5), Hemisphere (2) and Language or Group (2; where Language and Group were within-subjects and between-subjects factors, respectively).

The earliest PC marginally sensitive to experimental manipulations had its highest loadings (amplitude) between about 300 and 400 ms and explained 15.8% of the total ERP variance. Although the ANOVA containing the factor Language on the scores of this PC found no reliable effects involving Violation, the ANOVA containing the factor Group and all three violation
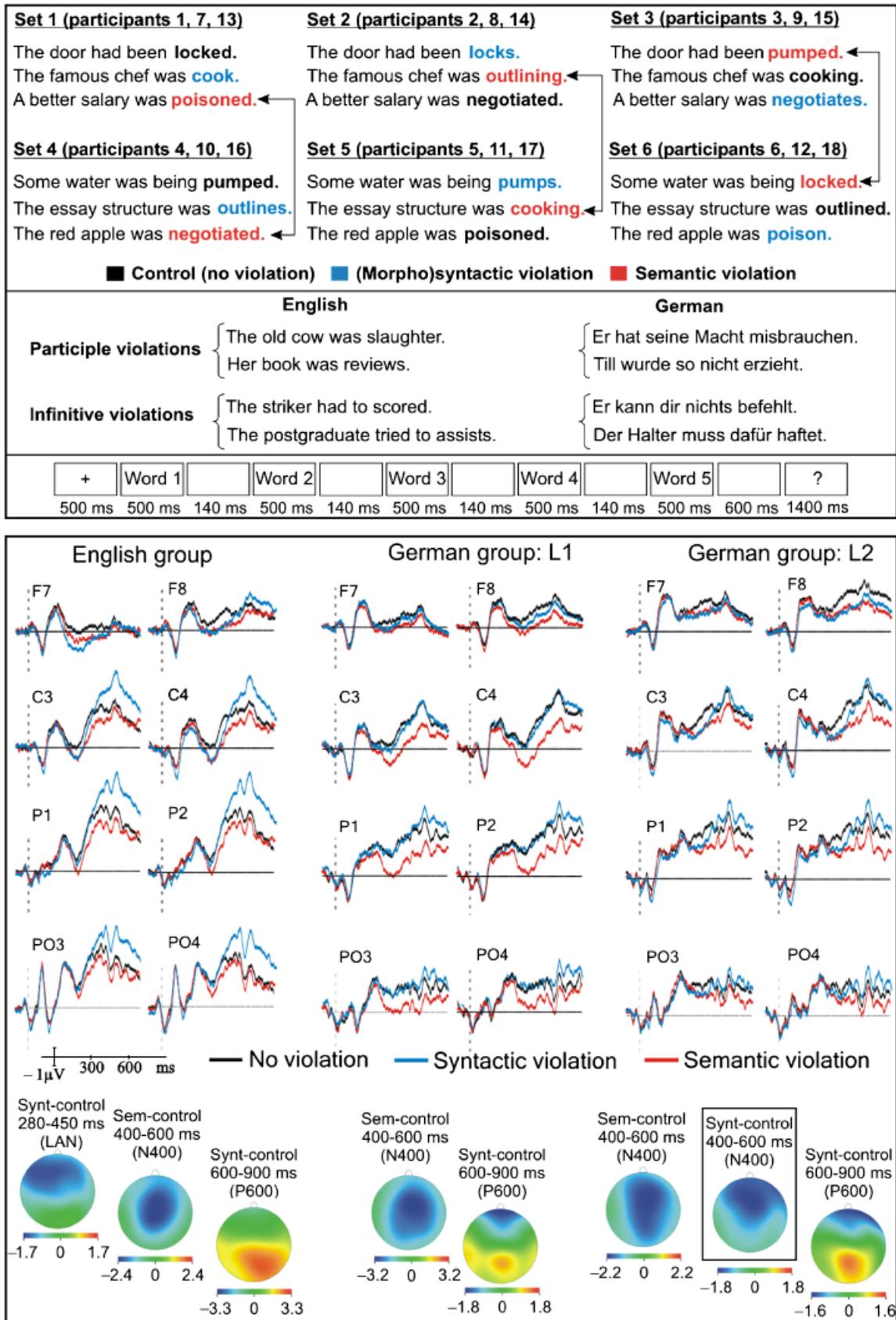
Figure 1. Top panel: The structure of the sentence sets, the types of verb inflection violations employed, and the time course of one trial. Lower panel: ERPs in selected electrodes and spline-interpolated scalp distributions of temporal ranges associated with statistically reliable differences. The topography of the N400 morphosyntactic effect in L2 is outlined. Both ERP waveforms and scalp distributions are shown referenced to the linked ears to facilitate comparisons with previous studies.
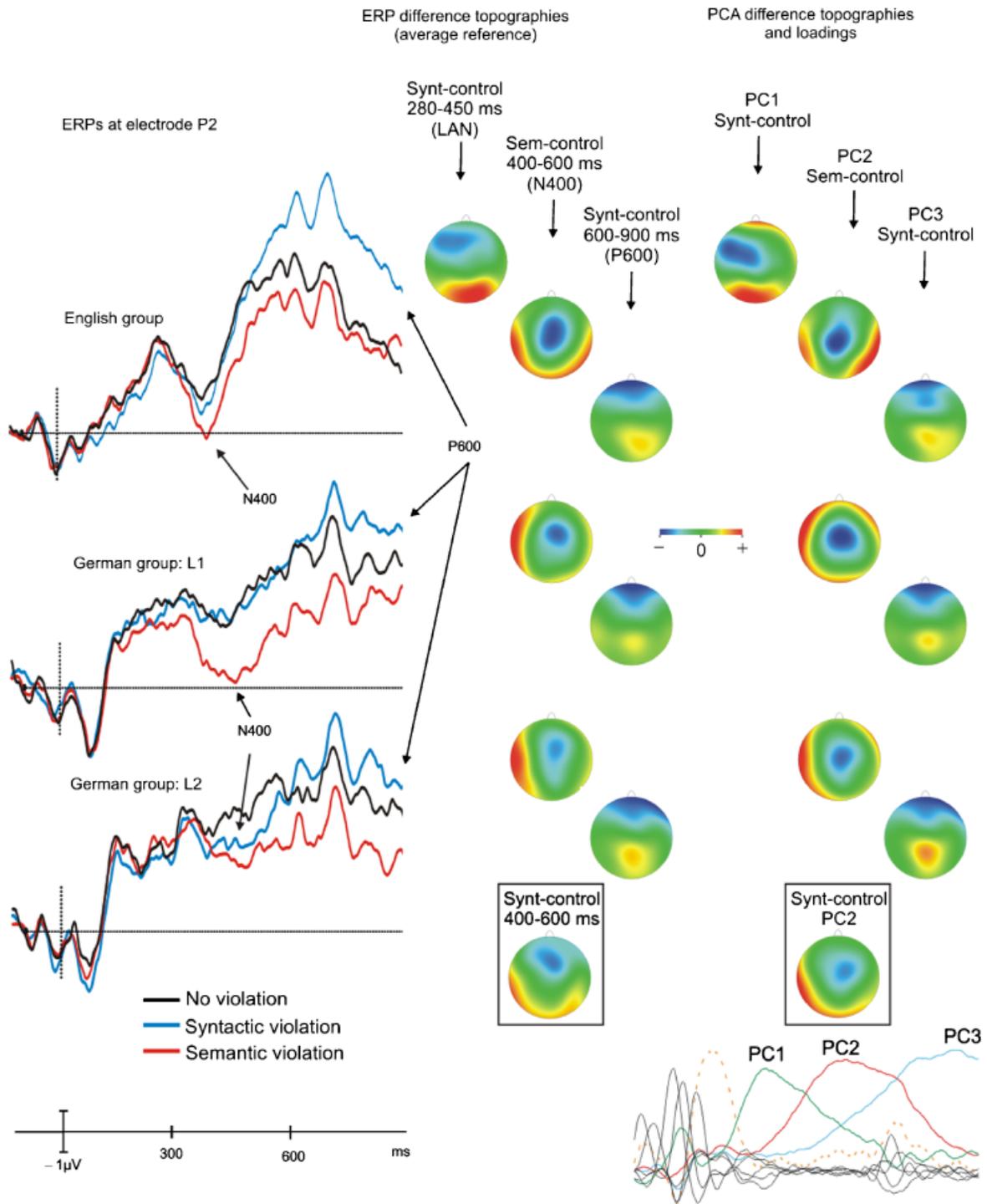
Figure 2. Left: ERPs at a representative parietal electrode (P2). Middle: Scalp distributions of experimental effects, average referenced for comparisons with the same effects in PCA components. The effect of the average reference is to balance the positive and negative poles of scalp distributions (see Figure 1 for the same topographies with ear referencing). For space economy, the exact scales are omitted, but they all adhere to the same color convention and are symmetric as in Figure 1. The topography of the N400 morphosyntactic effect in L2 is outlined. Right: Scalp distributions of statistically reliable differences in PCA components. Note that the topography of the syntactic (L2) N400 difference in the PCA is similar to the semantic N400 topographies (in the ERP and PCA). This suggests that the PCA has effectively "unmixed" the syntactic (L2) N400 effect from the neighboring/overlapping P600 effect. Loadings of principal components (PCs); PCs submitted to ANOVAs are shown in color in the lower right corner; those sensitive to experimental manipulations are labeled in temporal order (as described in the text).

levels found a marginally reliable Violation × Region × Group interaction, $F(8,272) = 2.22$, $p = .07$, $\varepsilon = .48$, $\eta^2_p = .06$. The reliability of the same interaction in the follow-up ANOVA contrasting the syntactic and control conditions, $F(4,136) = 3.45$, $p < .05$, $\varepsilon = .50$, $\eta^2_p = .09$, along with the syntactic-minus-control difference topography in this PC (see Figure 2), would appear to point to a greater syntactic LAN in the English group, relative to the German group, in which no discernable trend was observed in either L1, $F(1,17) = 0.09$, n.s., or L2, $F(1,17) = 0.57$, n.s. However, the LAN also failed to reach significance in the English subjects (effect of Violation: $F [1,17] = 2.58$, $p = .13$; Violation × Region interaction: $F [4,68] = 2.61$, $p = .09$).

The second (in temporal order) PC sensitive to violation type explained 25.3% of variance, had its highest loadings in the 400–650-ms range, and showed a topography of the semantic versus control difference closely mirroring that observed in the raw ERPs in the corresponding (N400) time range (see Figure 2). When all three violations were entered into the analysis, the ANOVA containing the factor Language found a reliable main effect of Violation and a reliable Violation × Region interaction, $F(2,34) = 7.75$, $p < .01$, $\varepsilon = .86$, $\eta^2_p = .31$; $F(8,136) = 2.64$, $p < .05$, $\varepsilon = .52$, $\eta^2_p = .13$, as did the ANOVA containing the factor Group, $F(2,68) = 6.80$, $p < .01$, $\varepsilon = .97$, $\eta^2_p = .17$; $F(8,272) = 4.06$, $p < .01$, $\varepsilon = .53$, $\eta^2_p = .11$. ANOVAs contrasting the semantic and control conditions found a significant main effect of Violation and a Violation × Region interaction: with factor Language, $F(1,17) = 23.71$, $p < .001$, $\eta^2_p = .58$; $F(4,68) = 4.08$, $p < .05$, $\varepsilon = .43$, $\eta^2_p = .19$; with factor Group, $F(1,34) = 18.22$, $p < .001$, $\eta^2_p = .35$; $F(4,136) = 5.21$, $p < .05$, $\varepsilon = .56$, $\eta^2_p = .13$. Intriguingly, the same temporal PC that captured the N400 effect in semantic violations in both languages/groups showed a similar effect in morphosyntactic violations, but only in L2. ANOVAs (containing the Language factor) on the syntactic and control conditions found a reliable effect of Violation, $F(1,17) = 4.76$, $p < .05$, $\eta^2_p = .22$, and a marginally reliable Violation × Language interaction, $F(1,17) = 3.96$, $p = .06$, $\eta^2_p = .19$. The follow-up ANOVA contrasting syntactic violations and control items in German subjects found a reliable main effect of Violation and a Violation × Region interaction in their L2, $F(1,17) = 8.67$, $p < .01$, $\eta^2_p = .34$; $F(4,68) = 4.10$, $p < .05$, $\varepsilon = .58$, $\eta^2_p = .19$, but not in their L1 ($p > .25$); these effects also failed to materialize in English subjects ($p > .2$).

The third experimentally sensitive PC (highest loadings in the 650–900-ms range; 27.4% of ERP variance explained) had a scalp distribution of the syntactic versus correct effect closely resembling that of the raw ERPs in the P600 range (see Figure 2). The ANOVA containing the factor Language and all Violation conditions found a reliable Violation × Region interaction, $F(8,136) = 5.52$, $p < .01$, $\varepsilon = .39$, $\eta^2_p = .24$, followed by a reliable Violation × Region interaction in the ANOVA that contrasted the syntactic and control conditions, $F(4,68) = 6.21$, $p < .01$, $\varepsilon = .39$, $\eta^2_p = .28$, and no reliable effects in the ANOVA on the semantic and control conditions. The Violation × Region interaction reflects more positive-going voltages in syntactic violations, relative to well-formed sentences over the posterior scalp and the converse over the anterior scalp, consistent with the distribution of P600 (see Figures 1 and 2). Note that the effect of the average reference is to balance the positive and negative poles of scalp distributions. Thus, its effect on the ear-referenced distribution of the P600 containing a pronounced positivity and a weaker negativity (see Figure 1) is that the positivity is somewhat attenuated and the negativity somewhat enhanced, without

a change in the difference between the minimum and the maximum (see Figure 2). The ANOVA containing the factor Group and all Violation conditions similarly revealed a reliable Violation × Region interaction, $F(8,272) = 7.25$, $p < .001$, $\varepsilon = .36$, $\eta^2_p = .18$, followed by a reliable main effect of Violation and a Violation × Region interaction in the ANOVA that contrasted the syntactic and control conditions, $F(1,34) = 4.74$, $p < .05$, $\varepsilon = .36$, $\eta^2_p = .12$; $F(4,136) = 7.53$, $p < .01$, $\varepsilon = .39$, $\eta^2_p = .18$, and no reliable effects in the ANOVA on the semantic and control conditions. Although for all of the above P600 effects there were no reliable interactions between the factors Violation and Language/Group, a syntactic versus control ANOVA was run to assess the reliability of P600 in L2 specifically, resulting in a reliable main effect of Violation and a significant Violation × Region interaction, $F(1,17) = 4.47$, $p < .05$, $\eta^2_p = .21$; $F(4,68) = 5.92$, $p < .01$, $\varepsilon = .44$, $\eta^2_p = .26$.

It is important to mention that the PCA found no component with sustained loadings throughout the 200–900-ms range to account for the apparent sustained anterior negativity in all violations versus control (see Figure 1). We therefore conclude that this protracted anterior negativity in the ERP resulted from the summation of negative polarity regions in the scalp distributions of different (uncorrelated in the PCA) components, as well as the LAN trend in the English group. Another issue to note is that long-latency temporal PCs such as the ones identified here, though useful for component identification, are less informative regarding the exact onset of ERP differences. To examine onset differences, we therefore ran Violation (2) × Language (2) × Time Window (2) × Region (5) × Hemisphere (2) ANOVAs on raw ERP stretches selected to encompass the onset of N400/P600 in both languages and groups; the Time Window factor had two levels: N400, 350–425 ms and 425–500 ms; P600, 600–700 ms and 700–800 ms. Neither for N400 nor for P600 did the critical Violation × Language × Time Window interaction approach significance ($ps > .15$).

Discussion

The present study aimed to use both within-subject and between-subjects contrasts to examine an electrophysiological response elicited by morphosyntactic violations (P600) when the morphological features under scrutiny in L2 are present in the subjects' L1. Our finding of a P600 in L2 that was statistically indistinguishable from that in L1, taken together with reports of P600 absence in highly proficient Japanese–English bilinguals (Ojima et al., 2005; see the introduction), suggests that the morphosyntax of L1 shapes the sensitivity to similar morphosyntactic features in L2. Can one conclude then that the processing of such features in L2 is qualitatively equivalent to that in L1? We found a trend toward a greater LAN in the morphosyntactic condition in L1 in English subjects, relative to L2. However, given the absence of a similar discernable trend in the German subjects' L1 and its failure to reach significance in the English subjects, we hesitate to interpret this as an L1 versus L2 difference.

An intriguing outcome was the N400-like negativity in response to morphosyntactic violations in L2—an effect we found neither in the same subjects' mother tongue nor in the English group (see waveforms in Figure 2, left). The fact that the same PCA component explained the variance in this ERP negativity as well as in the N400 in response to semantic violations in L1

(in both groups) and L2 conditions suggests that the syntactic negativity in the N400 range is indeed an N400 (see Figure 2, bottom). How would one explain it? One account (Ullman, 2001) posits that morphological segmentation processes (affix stripping and concatenation), which are fast and automatic in L1 (cf. Lavric, Clapp, & Rastle, 2007), are less developed in L2. It is possible that L2 may be accompanied by more reliance on nonsegmented representations of morphologically complex forms (*cleaning*, instead of *clean+ing*), and that greater involvement of the lexico-semantic system in the processing of the morphosyntactic anomaly leads to N400 enhancement in L2. A related proposal was made recently by Osterhout, McLaughlin, Pitkänen, Frenck-Mestre, and Molinaro (2006), whose longitudinal investigation of the acquisition of morpho-syntax in L2 shows that in the early stages morphosyntactic violations elicit an N400, rather than a P600. However, these authors found that their morphosyntactic N400 could not be seen after 3 months of instruction (it was replaced by the "appropriate" P600), whereas we observed it in reasonably fluent bilinguals years following the onset of L2 learning, with a P600 effect also present in the ERP.

We are more inclined to interpret this effect as a consequence of the interaction between morphosyntactic and sentence wrap-up processes. Since violations in the current design were confined to the sentence-final position, all outcomes (including the syntactic N400) were associated with processing the final word. Final words in sentences containing violations at an earlier position (semantic or syntactic) have been previously reported to elicit N400-like negativities, thought to reflect increased semantic integration (wrap-up) demands (cf. Hagoort, 2003; Hagoort et al., 1993; Osterhout & Nicol, 1999). Although we found no such wrap-up effects in the syntactic condition in either L1 data set, it seems likely that weaker/slower morphosyntactic processes in L2 exacerbated the pressures on the wrap-up semantic integration mechanism, leading to an N400 in the syntactic condition in L2. This account is consistent with the findings that (in L1) the consequences of a semantic violation on the N400 amplitude are boosted by an additional syntactic violation (Hagoort, 2003), and that the effect of a syntactic violation on the N400s seen in the words at the end of the sentence can vary (Hagoort et al., 1993). An interesting corollary of this account is that the wrap-up N400 may be enhanced in individuals with weaker/slower morphosyntactic processing even in their L1.[1]

Further efforts will be needed to decide between the above conjectures.

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