Proficiency Differences in Syntactic Processing of Monolingual Native Speakers Indexed by Event-related Potentials

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Abstract

■ Although anecdotally there appear to be differences in the way native speakers use and comprehend their native language, most empirical investigations of language processing study university students and none have studied differences in language proficiency, which may be independent of resource limitations such as working memory span. We examined differences in language proficiency in adult monolingual native speakers of English using an ERP paradigm. ERPs were recorded to insertion phrase structure violations in naturally spoken English sentences. Participants recruited from a wide spectrum of society were given standardized measures of English language proficiency, and two complementary ERP analyses were performed. In between-groups analyses, participants were divided on the basis of standardized proficiency scores into lower proficiency and higher proficiency groups. Compared with lower proficiency participants, higher proficiency participants showed an early anterior negativity that was more focal, both spatially and temporally, and a larger and more widely distributed positivity (P600) to violations. In correlational analyses, we used a wide spectrum of proficiency scores to examine the degree to which individual proficiency scores correlated with individual neural responses to syntactic violations in regions and time windows identified in the between-groups analyses. This approach also used partial correlation analyses to control for possible confounding variables. These analyses provided evidence for the effects of proficiency that converged with the between-groups analyses. These results suggest that adult monolingual native speakers of English who vary in language proficiency differ in the recruitment of syntactic processes that are hypothesized to be at least in part automatic as well as of those thought to be more controlled. These results also suggest that to fully characterize neural organization for language in native speakers it is necessary to include participants of varying proficiency. ■

INTRODUCTION

Anecdotally, it appears that there exist differences in the way native speakers use and comprehend their native language. Beginning with Chomsky's (1965) claim that linguistic theory should be concerned with an ideal speaker–listener with perfect linguistic knowledge, differences in linguistic proficiency among native speakers have often been assumed to be the result of resource limitations or performance errors considered to be independent of and irrelevant to grammatical knowledge. Numerous studies of bilinguals, young children, children with specific language impairment, and deaf adults have found that event-related potentials (ERPs) are sensitive to differences in language proficiency (Weber-Fox & Neville, 1996; Mills, Coffey-Corina, & Neville, 1993; Neville, Coffey, Holcomb, & Tallal, 1993; Neville, Mills, & Lawson, 1992).

In addition, several ERP studies have examined differences in language processing in native speakers. However, most of these studies have not separately assessed confounds between language processing and other cognitive resource limitations because they specifically studied

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complex syntactic structures to examine individuals with differences in working memory (WM) capacity (Vos & Friederici, 2003; Vos, Gunter, Kolk, & Mulder, 2001; Vos, Gunter, Schriefers, & Friederici, 2001; Friederici, Steinhauer, Mecklinger, & Meyer, 1998; King & Kutas, 1995; Mecklinger, Schriefers, Steinhauer, & Friederici, 1995). Also, most of these latter studies looked at university students processing sentences in the visual modality. Because the majority of language use in everyday life occurs in the auditory modality and between speakers with a wide variety of educational backgrounds, there remains the question of the extent to which proficiency differences in syntactic processing may be apparent under conditions that more closely approximate real-world language use. In the current study, we tested the hypothesis that differences in grammatical proficiency in native speakers are indexed by differences in ERP components related to the processing of phrase structure violations in auditorily presented sentences. To this end, we examined differences in grammatical processing proficiency in participants recruited from a wide spectrum of society using a natural speech paradigm that does not place high demands on WM resources. To more fully characterize these differences, we conducted two

complementary analyses: First, we characterized differences in the ERP response to syntactic violations between two groups that differed in standardized proficiency scores; and second, we conducted correlational analyses with a larger group of participants to assess the degree to which the relationship between proficiency and the neural response to syntactic violations held across a wide spectrum of proficiency scores while controlling for other possible mediating factors.

ERP Studies of Language Processing

ERPs provide an on-line, multidimensional index of cognitive processes with a temporal resolution of milliseconds and thus have emerged as one of the more widely used methodologies to examine on-line language processing. Along with other methods, ERP studies have demonstrated that separate linguistic subsystems are mediated by nonidentical neural mechanisms. Numerous studies in both the visual and the auditory modalities have found that semantically unexpected words elicit a negative-going potential peaking around 400 msec (N400) compared with contextually appropriate words (e.g., Friederici, Pfeifer, & Hahne, 1993; Holcomb & Neville, 1991; Kutas & Hillyard, 1980), leading to the hypothesis that the N400 component indexes semantic processes of lexical integration.

Although the N400 has consistently been related to aspects of semantic processing, at least two components have been identified that index syntactic processing. One of these is a negative-going wave, typically larger over left anterior electrode sites between 100 and 500 msec, known as the left anterior negativity (LAN). The LAN has been elicited by a variety of syntactic violation types, such as phrase structure violations (Yamada & Neville, 2007; Gunter, Friederici, & Hahne, 1999; Hahne & Friederici, 1999; Friederici et al., 1993; Neville, Nicol, Barss, Forster, & Garrett, 1991) and morphosyntactic violations (Coulson, King, & Kutas, 1998a; Friederici et al., 1993; Münte, Heinze, & Mangun, 1993). The LAN typically occurs in one or both of two time windows (100–300 and 300–500 msec), which has lead some researchers to propose the existence of two distinct, separate components, with the first termed the early LAN (ELAN), indexing processes different from those indexed by the second LAN (Hahne & Jescheniak, 2001; Friederici & Mecklinger, 1996; Friederici, 1995). Two recently proposed theories of on-line sentence processing account for these components in different ways. Friederici (2002) proposes that the ELAN reflects early and automatic processing of word category violations, a process hypothesized to be autonomous and independent of contextual or semantic influences. In contrast, Hagoort (2003, 2005) and van den Brink and Hagoort (2004) propose that semantic and syntactic information are processed in parallel as soon as they are available and that the timing differences reported between LAN and ELAN effects are a result of differences in the on-line availability of morphosyntactic and word category information, not as the result of a fundamental functional distinction between them.

The second component that has been observed in ERP studies of syntactic processing is a large positive-going wave usually largest over bilateral posterior regions and peaking between 500 and 1000 msec, known as the P600 (Osterhout & Holcomb, 1993). The P600 is consistently elicited by syntactic violations (Hagoort & Brown, 2000; Hahne & Friederici, 1999; Osterhout & Mobley, 1995; Hagoort, Brown, & Groothusen, 1993; Osterhout & Holcomb, 1992) as well as by violations of preferred syntactic structure (Osterhout, Holcomb, & Swinney, 1995; Osterhout & Holcomb, 1992) or in well-formed sentences of higher syntactic complexity (Kaan & Swaab, 2003a, 2003b; Kaan, Harris, Gibson, & Holcomb, 2000). Although the distribution of the P600 is usually posterior, several studies have reported a late positivity with a more frontal distribution to grammatically correct but nonpreferred structures (Kaan & Swaab, 2003a, 2003b; Friederici, Hahne, & Saddy, 2002; Osterhout & Holcomb, 1992). This has led to the proposal that the frontally distributed P600 reflects processing difficulties related to revision in the face of nonpreferred structures, whereas the posteriorly distributed P600 reflects processes related to the failure of a parse and related processes of repair and meaning rescue (Friederici et al., 2002; Hagoort & Brown, 2000) or to syntactic integration difficulty (Kaan et al., 2000).

Although overall there is a good deal of consistency in the elicitation of this biphasic response across studies using different violation types in different languages and modalities, there still exists a great deal of variability, in particular with regard to the distribution of the anterior negativity effect. Specifically, several studies have reported an anterior negativity effect in monolingual native speakers, which is more extended temporally and/or more bilateral in distribution (e.g., Isel, Hahne, Maess, & Friederici, 2007; Rossi, Gugler, Friederici, & Hahne, 2006; Hagoort, Wassenaar, & Brown, 2003; Hahne & Friederici, 2002; Hahne, 2001; Hahne & Jescheniak, 2001; Friederici & Frisch, 2000; Münte, Matzke, & Johannes, 1997; Friederici & Mecklinger, 1996; Friederici et al., 1993). Although possible sources of this variability are potentially informative for theories of on-line sentence processing, little is known about this issue. One possible source of this variability is within-group differences in participant characteristics, such as language proficiency. Although it is difficult to assess the possibility that such differences may have contributed to the variability observed in previous studies, here we specifically address the possibility that differences in participant characteristics may be reflected in differences in the distribution and timing of ERPs elicited by syntactic violations.

Individual Differences and Effects of Experience

Previous studies of individual differences in adult native speakers have primarily focused on differences in WM

using paradigms involving garden-path sentences or manipulations of syntactic complexity. Early behavioral studies found that individual differences in WM capacity are predictive of comprehension and speed of processing, as subjects with lower WM spans were slower and less accurate in comprehending complex syntactic constructions compared with subjects with higher WM spans (Just & Carpenter, 1992; King & Just, 1991). Subsequent ERP studies have found that these differences are reflected electrophysiologically as well. The most common finding is that the disambiguating element in object-first relative clauses compared with subject-first relative clauses elicits a P600, but only in subjects who performed faster on sentence comprehension tasks (Mecklinger et al., 1995) or who had high WM spans (Vos & Friederici, 2003; Friederici et al., 1998). Although these studies provide evidence that ERPs are sensitive to individual differences in WM and syntactic processing, the focus on differences in WM raises the question of the degree to which individual differences in proficiency may occur independently of other resource limitations such as WM span.

Several studies of both monolingual native speakers and bilinguals suggest that language experience affects both linguistic proficiency and related neural systems indexed in ERP paradigms. ERP studies of monolingual children suggest that brain organization is predicted by language proficiency: Children with larger vocabularies (Mills et al., 1993) and children who score higher on tests of language comprehension (Adamson-Harris, Mills, & Neville, 2000) show more mature patterns of brain organization for language, including greater focalization, as compared with children with smaller vocabularies or those who score lower on comprehension tests. ERP studies of deaf adults suggest that the effects of early language experience can endure into adulthood, as individuals exposed to American Sign Language (ASL) from an early age recruit right hemisphere areas in addition to left hemisphere language areas when processing ASL. However, those not exposed to ASL at an early age do not show this bilateral response to ASL and score lower on tests of ASL grammar (Newman, Bavelier, Corina, Jezzard, & Neville, 2002; Neville, Coffey, Lawson, Fischer, et al., 1997; Newport, 1990). More evidence from ERP studies of bilinguals suggest that linguistic subsystems are differentially sensitive to the effects of language experience, with the syntactic subsystem displaying less focal neural organization with delays in second language exposure as short as 4–6 years, whereas the semantic subsystem appears to be affected by delays in second language exposure only after 11–13 years of age (Weber-Fox & Neville, 1996). Similar results have been observed for native and late learners of ASL (Capek et al., 2002, 2009).

This evidence of the effects of language experience raises the question of the extent of these effects. Do significant differences in proficiency exist within normal monolingual adults, and would such differences be indexed by ERP components related to syntactic process-

ing? Or do effects of early experience fade with time such that neural systems underlying language processing in adult monolinguals are relatively homogeneous?

Data from one ERP experiment suggest that significant differences in proficiency do exist in monolingual adults and are linked to altered neural organization as indexed by ERPs. Weber-Fox, Davis, and Cuadrado (2003) found that individuals who scored higher on a spoken grammar test had an earlier N280 to closed-class words over left anterior regions, suggesting greater efficiency related to syntactic processing in higher proficiency individuals. If ERP components associated with syntactic processing are sensitive to differences in linguistic proficiency, then the evidence discussed above raises the hypothesis that components elicited by phrase structure violations in low proficiency participants should be less focal than those elicited in higher proficiency individuals.

The Present Study

The present study further explored the relationship between proficiency and neural organization for language in monolingual native speakers as measured by ERPs during on-line syntactic processing. We attempted to maximize proficiency differences by recruiting participants from a wide spectrum of society. We attempted to minimize the effects of other potential resource limitations such as WM by using a paradigm that examined the brain response to phrase structure violations in simple, single-clause sentences, which were presented auditorily in an attempt to increase ecological validity while minimizing confounds related to literacy. In an effort to more fully characterize differences in neural organization related to proficiency, we conducted two complementary analyses. In the first, we examined two groups of participants with scores at or near the upper and lower quartiles on standardized tests of English proficiency. In the second, we examined the relationship between the proficiency and the neural response to syntactic violations in a group of 72 participants with a wide range of proficiency scores, using a correlational approach that allowed us to control for other possible mediating factors including education level, WM span, and socioeconomic status (SES) of origin.

METHODS

Participants

Right-handed, normal hearing, native monolingual speakers of English, recruited from both the university and the nonuniversity populations, participated in the study. Participants were paid for their time. A total of 116 participants were run in the behavioral testing paradigm described below, and of these 80 were also run in the ERP paradigm described below. From this group of 80, 8 participants were removed from the final analysis either after being identified as outliers on the behavioral measures or because of

excessive ERP artifact. This left a group of 72 participants with good behavioral and ERP data, and from this group 34 were selected for the between-groups analyses on the basis of behavioral performance to form lower proficiency (LP; $N = 17$) and higher proficiency (HP; $N = 17$) groups. An average standardized score for the three subtests of the Test of Adolescent and Adult Language, Third Edition (TOAL-3; Hammill, Brown, Larsen, & Wiederholt, 1994) was calculated for all participants, and the LP and HP groups were formed by selecting the participants with the lowest and highest average standardized scores. To reduce group differences in WM capacity, we modified an initial selection of the participants with the lowest and highest average standardized scores by removing the two participants from each group with the lowest and highest Carpenter Reading Span scores, respectively.

Behavioral Language Inventories

Three subtests of the TOAL-3 were administered to assess proficiency. The TOAL-3 Listening/Vocabulary subtest is a test that requires participants to match a vocabulary word with two pictures relating to that word (out of four pictures shown). The TOAL-3 Listening/Grammar subtest requires participants to determine, out of three sentences presented auditorily, which two sentences have similar meaning. The TOAL-3 Speaking/Grammar subtest requires participants to repeat exactly sentences said by the examiner; the sentences gradually increase in syntactic difficulty. Participants were also given the Saffran and Schwartz Grammaticality Judgment Test (Linebarger, Schwartz, & Saffran, 1983), a 78-item assessment in which participants are asked to judge the grammaticality of sentences containing a variety of syntactic violations, adapted for purposes of this study into the auditory modality. To assess WM capacity, we also gave participants the Carpenter Reading Span Test (Daneman & Carpenter, 1980), a widely used assessment in which participants must recall the final word of two or more sentences after reading them consecutively. Participants also completed a questionnaire that gathered data about educational attainment as well as about language usage, television, and video game habits both as children and as adults. This questionnaire also gathered data used to calculate the SES of the family in which participants were raised until 18 years of age or independence. This was measured by the Hollingshead Four Factor Index of Social Status (Hollingshead, 1975), which takes into consideration parental education and occupation.

Stimuli

In the ERP paradigm, participants heard both English sentences and Jabberwocky sentences, in which open-class words were replaced with pronounceable nonwords to greatly reduce the semantic context; only the results for the English stimuli are presented here. The English stimuli were sentences that were canonical (50%) or that contained an insertion phrase structure violation (50%) in which an additional closed-class word was inserted in a sentence-final prepositional phrase. In all cases, the phrase structure violation clearly occurred at the onset of either a demonstrative (50%) or a possessive (50%) pronoun directly following the inserted pronoun. The ERPs to the onset of the target word (italicized below) in the canonical and violation (*) sentences were compared:

English: Timmy can ride the horse at *his* farm.
          *Timmy can ride the horse at my *his* farm.

A number of measures were undertaken to provide prosodic variability as well as to ensure that subjects listened fully to the sentences and did not focus only on the location of the critical violation. In 5% of the experimental sentences, an additional prepositional phrase was added to the beginning of the sentences, and in 20% of the experimental sentences, an adjective was placed directly after the target word so that the target word was not invariably in the penultimate position in the sentence. In addition, filler sentences and probe questions were constructed. Filler sentences contained a permutation phrase structure violation in which a main verb and the determiner of the object noun phrase were reversed. Probe questions took the form "Did you hear the word (*blank*)?" Most participants heard 62 sentences of each condition; a subset ($N = 10$) heard 40 sentences per condition. Filler sentences (10% of total) were pseudorandomly interspersed between the experimental sentences, as were probe questions (5% of total), such that filler sentences and probe questions occurred equally across quarter stimulus blocks and were always separated by at least two experimental sentences.

All sentences were recorded using SoundEdit 16 Version 2 with 16-bit resolution and a 16-kHz sampling rate then transferred to a PC for presentation. The sentences were spoken by a female with natural tempo and prosody, and critical word onsets were identified and coded by three trained coders using both auditory cues and visual inspection of sound spectrographs for increased accuracy. Any sentences in which codes differed by more than 20 msec between coders were recoded by all three coders together until a consensus was reached by all three to ensure reliability.

Procedure

Most participants were tested in one 3-hour session, with the standardized tests of language administered right before ERP testing. A subset of participants ($N = 24$) were given the behavioral measures and ERP testing in separate sessions. In each ERP session, a 32-channel electrode cap was applied while the participant completed an information sheet, which included questions about their education, SES, handedness, neurological history, and language habits. Participants were then seated in a comfortable chair in an electrically shielded, sound-attenuating

booth. Sentences were presented via a speaker placed centrally on a monitor 70 in. from the participant. Participants were given auditory instructions including examples of both sentence types and emphasizing the need to judge the sentences on the basis of grammatical, and not semantic, correctness. On each trial, participants pushed one of two response buttons to play a sentence. While the sentences were playing, participants were asked to refrain from blinking or moving their eyes as a box with a central fixation cue ("*") was displayed. After each sentence, participants were cued to make a judgment with a display of "Yes or No?" on the screen. The judgment was made with a button press with either the left or the right hand, counterbalanced across participants. Participants proceeded at their own pace and were given two regularly scheduled breaks and additional breaks as requested.

EEG Equipment and Analysis

The EEG was recorded using tin electrodes mounted in an appropriately sized elastic cap (Electro-Cap International) over 29 scalp sites on the basis of the Standard International 10–20 electrode locations: F7/F8, F3/F4, FT7/FT8, FC5/FC6, T3/T4, C5/C6, CT5/CT6, C3/C4, T5/T6, P3/P4, TO1/TO2, O1/O2, FP1/FP2, Fz, Cz, and Pz. Scalp electrode impedances were kept below 3 kΩ. Data from all scalp electrodes were referenced on-line to the EEG from an electrode placed over the right mastoid and later referenced off-line to the mathematical average of the left and right mastoids. Horizontal eye movements were monitored using electrodes placed at the outer canthus of each eye and referenced to each other, whereas vertical eye movements were monitored using an electrode placed beneath the right eye and referenced to the right mastoid. The raw EEG signal was collected at a sampling rate of 250 Hz and was amplified using Grass Amplifiers with high- and low-pass filter settings of 0.01 and 100 Hz, respectively.

Only trials on which subjects responded correctly were included in the ERP analyses. The EEG data for each participant were examined for eye movements, muscle artifact, and amplifier saturation and drift, and any trials contaminated by these artifacts were excluded from final data analyses. ERPs were computed for 1200 msec after the onset of the target word relative to a 100-msec prestimulus baseline. ERP waveforms were measured within specific time windows determined by visual inspection of individual and group averages; specific time windows are described in the Results section. On the basis of *a priori* hypotheses from previous studies and on visual inspection of the effects, the anterior negativity effect was characterized by analyzing the 12 anterior electrode sites. Additional analyses conducted on different time windows and electrode sites are noted in the Results section.

For the between-groups analyses, mean voltage amplitude was measured within each time window and ana-

lyzed using ANOVAs with repeated measures, including two levels of condition (C: canonical, violation), two levels of hemisphere (H: left, right), three levels of anterior-posterior (A: frontal, fronto-temporal, temporal [anterior sites]; central, parietal and occipital [posterior sites]), and two levels of lateral-medial (L: lateral, medial) as well as a between-participants factor, proficiency (P), with two levels (LP and HP). Following omnibus ANOVAs, additional analyses were performed in step-down fashion to isolate any significant interactions, collapsing across factors with which an interaction was not found. When significant between-groups interactions were found, separate ANOVAs were performed for each group to better characterize group differences. For all distributional comparisons, analyses were performed on both the raw data and the data normalized following the procedure recommended by McCarthy and Wood (1985); as no differences between the two analyses were found, only analyses performed on the raw data are reported. Greenhouse–Geisser corrections were applied to all ANOVAs with greater than one degree of freedom.

For correlational analyses, for each of the 72 participants the average difference amplitude (violation − canonical) was calculated for each electrode site. On the basis of the results from the between-groups analyses, three time windows were analyzed to capture the anterior negativity: 100–300, 300–700, and 700–1200 msec. Within these time windows, the average difference amplitude was calculated across left anterior lateral sites (F7, FT7, T3), left anterior medial sites (F3, FC5, C5), right anterior medial sites (F4, FC6, C6), and right lateral sites (F8, FT8, T4). A laterality index was also calculated for anterior lateral sites (left anterior lateral − right anterior lateral), anterior medial sites (left anterior medial − right anterior medial), and anterior sites (left anterior − right anterior). The 300- to 1000-msec time window was analyzed to capture the P600 effect; within this time window, the average difference amplitude was calculated across all 12 posterior sites. Zero-order correlations were then calculated between individual average difference amplitudes and individual proficiency scores, quantified as a composite individual average standardized score for the three subtests of the TOAL-3. To control for the possible influence of other variables that significantly correlated with proficiency, we also conducted partial correlations controlling for these variables. Any correlations driven by extreme scores, as defined by lying more than two standard deviations from the mean, are not reported.

RESULTS: BETWEEN-GROUPS ANALYSES

Behavioral Results

LP and HP groups were determined by standardized scores on the two TOAL-3 subtests used as described in the Methods section. The mean average standardized scores for the resulting LP ($M = 8.09$, $SD = 1.65$) and HP ($M =$

13.06, SD = 1.20) groups were statistically independent, $t(32) = -10.04, p < .0001$. The mean scores for each behavioral measure are displayed in Table 1. Means for the groups were statistically independent for each language measure. Although the groups did not differ significantly on the measure of WM capacity, there was a trend toward a group difference. Although all participants were within normal limits for native speakers, the groups were distinct in terms of TOAL-3 standardized scores: The mean scores for the LP group were at or below the 34th percentile on each subtest (below the 25th percentile for the grammar subtests), whereas the mean scores for the HP group were at or above the 75th percentile for each subtest. In the ERP grammaticality judgment task, there was a trend for a higher percentage of correct responses by the HP group ($M = 98.64, SD = 1.45$) compared with the LP group ($M = 94.96, SD = 9.94$), which did not reach significance, $t(32) = 1.512, p = .14$. Scores on measures used to ensure that participants were listening to the entire sentence indicated that this was indeed the case. The HP group answered 100% of the probe questions correctly, and the LP group, while performing significantly worse, still answered 94.18% of the questions correctly, $t(32) = 2.411$, $p < .05$.

The mean average standardized scores for the groups correlated significantly with several personal history factors. Highest education level achieved correlated significantly with proficiency scores ($r = .632, p < .0001$), and the HP group had significantly more education than the LP group, $t(32) = 3.875, p < .01$. In addition, the SES of the family in which participants were raised until 18 years of age or independence was calculated. This was measured by the Hollingshead Four Factor Index of Social Status (Hollingshead, 1975), which takes into consideration parental education and occupation. Proficiency scores also correlated significantly with family SES ($r = .320, p <$

.05); although the HP group had a higher family SES, this difference did not reach significance.

ERP Results

The ERP data to the critical word in English sentences for both groups are shown in Figure 1. Visual inspection of the waveforms revealed clear patterns and clear differences between proficiency groups. Both groups displayed a biphasic response to phrase structure violations: an anterior negativity with onset around 100 msec and a posterior positivity peaking around 600 msec. In the HP group, the anterior negativity effect was short in duration and larger over left hemisphere sites. In contrast, the anterior negativity in the LP group was more extended temporally and spatially, with the effect extending beyond 400 msec and more prominent over right hemisphere sites than in the HP group. In addition, the anterior negativity effect extended to 1200 msec over lateral sites, and a late negativity began at 700 msec over medial sites for the LP group. Group differences were also evident in the P600 effect, which was larger and more broadly distributed in the HP group compared with the LP group.

Anterior Negativity

Analyses across anterior electrode sites in the 100- to 300-msec time window revealed a group interaction with the factors hemisphere and lateral-medial, $C \times H \times L \times P$, $F(1, 32) = 4.22, p < .05$, reflecting significant differences in the distribution of the anterior negativity effect across proficiency groups. These distributional differences are illustrated by voltage maps in Figure 2. The effect in the HP group was more lateralized to left hemisphere sites, in particular across medial sites, whereas the effect in the LP group was more widespread and bilat-

Table 1. Mean Scores by Proficiency

Group	TOAL-3 L-V***	TOAL-3 L-G***	TOAL-3 S-G***	Saffran and Schwartz**	Carpenter Span*
LP (n = 17, 7 Females)					
M (SD)	23.06 (5.69)	19.00 (7.98)	17.06 (3.36)	74.29 (3.08)	2.79 (.53)
Range	14–33	7–32	9–22	67–78	2–4
Percentile	37	25	16	N/A	N/A
HP (n = 17, 10 Females)					
M (SD)	31.18 (2.55)	30.71 (4.79)	22.59 (1.62)	76.12 (.992)	3.15 (.66)
Range	27–35	17–35	20–25	75–78	2–5
Percentile	84	75	91	N/A	N/A

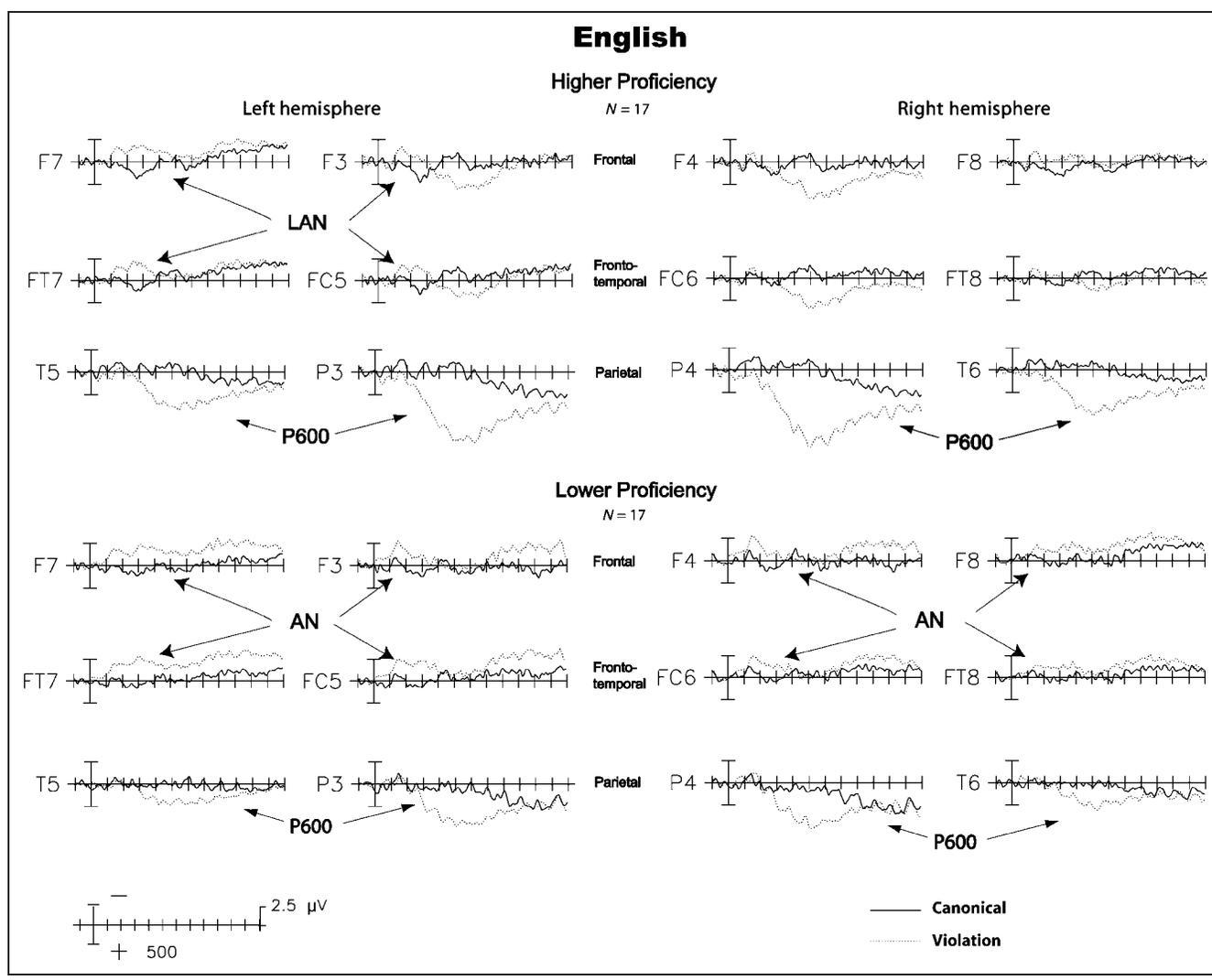*p = .095.

**p < .05.

***p < .0001.

Figure 1. ERPs to English phrase structure violations for HP and LP groups showing representative electrode rows illustrating the anterior negativity (frontal and fronto-temporal) and P600 (parietal) effects.

eral in distribution. Further analyses of this interaction confirmed this interpretation. In the HP group, the effect was significantly larger over left hemisphere sites overall, C × H, $F(1, 16) = 8.71$, $p < .01$, in the LP group, the effect was bilateral overall, C × H, $F(1, 16) = 1.81$, ns. Although there was a greater degree of left lateralization over lateral sites, C × H × L, $F(1, 16) = 4.65$, $p < .05$, in the LP group, a direct comparison of lateral sites by hemisphere did not reach significance, $t(16) = 1.762$, $p = .097$. These further analyses also confirmed distribution differences across lateral and medial sites, as there was a trend for the effect to be larger over lateral sites in the HP group, C × L, $F(1, 16) = 4.25$, $p = .056$, whereas it was evenly distributed across lateral and medial sites in the LP group, C × L, $F(1, 16) = 0.53$, ns.

Visual inspection also suggested group differences in the distribution of the negativity to the central row of electrodes (CT5-6, C3-4), and an interaction in the 100- to 300-msec time window across all electrode sites that neared significance confirmed that this effect extended to the central row, maximally over medial sites, in the LP group but not the HP group, C × A × L × P, $F(5, 160) = 2.72$, $p = .055$.

Late Negativity

As visual inspection suggested that the anterior negativity was longer in duration in the LP group, additional analyses across anterior sites were conducted in later time windows. A group interaction between 300 and 700 msec confirmed that the negativity extended in this time window in the LP group only, maximally over anterior-most lateral sites; in contrast, violations elicited a positivity maximal over medial sites in this time window in the HP group, C × A × L × P, $F(2, 64) = 6.27$, $p < .01$. As visual inspection revealed an anterior negativity in the 700- to 1200-time window in the LP group, additional analyses in this time window were conducted. These analyses confirmed that whereas the negativity extended across this epoch in the LP group, this was not the case in the HP
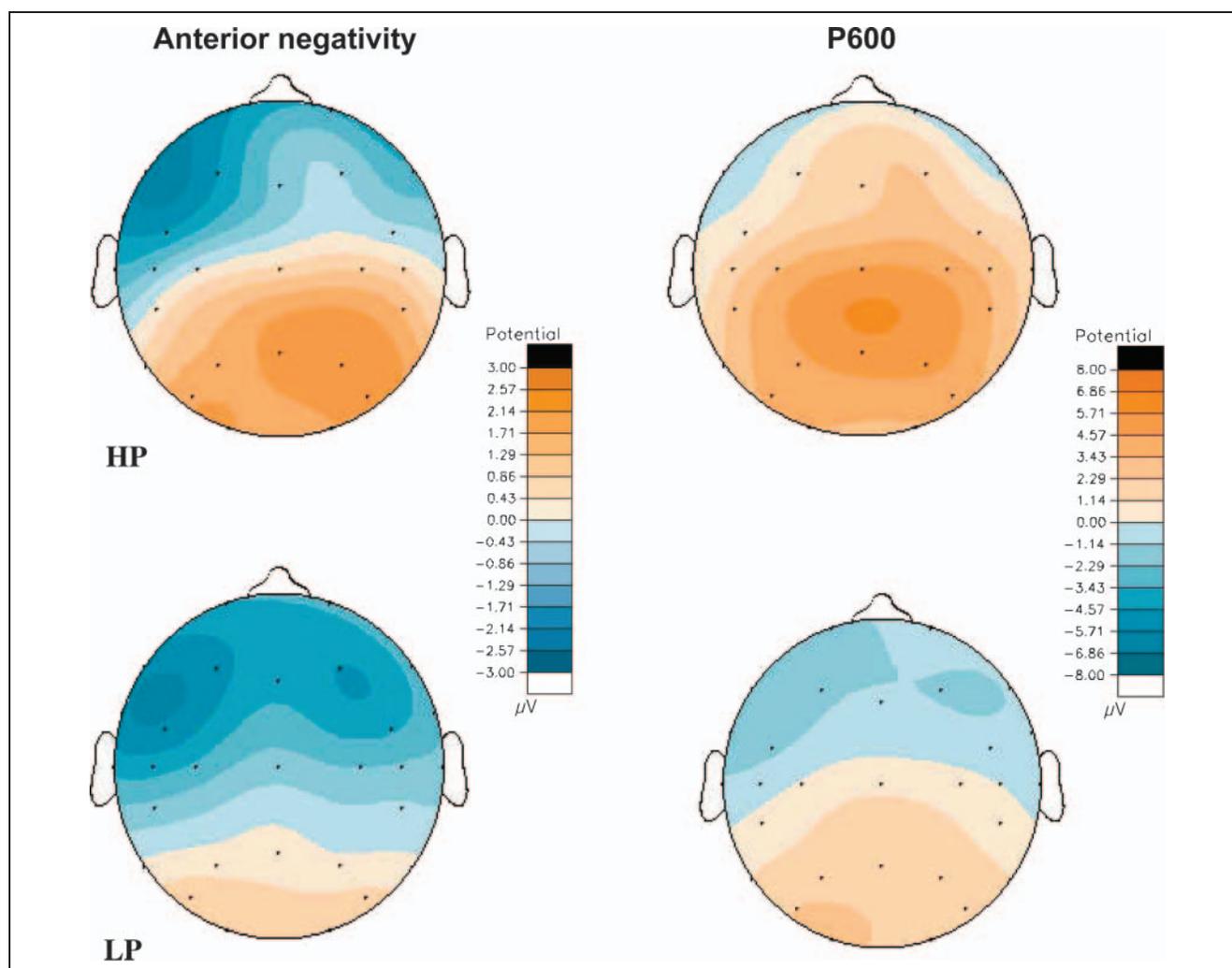
Figure 2. Voltage maps for HP and LP groups illustrating the distribution of the anterior negativity effect for English in over the 100- to 300-msec time window and the posterior positivity (P600) effect over the 300- to 1000-msec time window.

group, C × P, $F(1, 32) = 10.41$, $p < .005$. This negativity was bilaterally distributed in the LP group in both the 300- to 700-msec time window, C × H, $F(1, 16) = .281$, *ns*, and the 700- to 1200-msec time window, C × H, $F(1, 16) = .434$, *ns*.

Posterior Positivity (P600)

Because visual inspection suggested group differences in amplitude and distribution in the posterior positivity effect across all electrode sites, initial analyses were conducted across all sites. An analysis in the 300- to 1200-msec time window revealed that this effect was larger overall in the HP group than in the LP group, C × H, $F(1, 32) = 11.65$, $p < .005$, and that it extended to anterior medial sites in the HP group but not in the LP group, C × A × L × P, $F(5, 160) = 6.20$, $p < .005$.

As individual group analyses confirmed that the posterior positivity was confined to the three posterior rows in the LP group, C × A, $F(5, 80) = 27.66$, $p < .0001$, additional group comparisons limited to these rows were

conducted. These analyses revealed that the effect was larger in the HP group compared with the LP group over sites where the effect was present in both groups, C × P, $F(1, 32) = 8.24$, $p < .01$.

RESULTS: CORRELATIONAL ANALYSES

Behavioral Results

To limit the number of variables considered in the correlational analyses with average ERP difference amplitudes, we explored the relationship between proficiency and several potentially confounding variables. Proficiency correlated significantly with SES of origin ($r = .460$, $p < .0001$), WM span ($r = .561$, $p < .0001$), and education level ($r = .368$, $p < .005$). Proficiency did not correlate significantly with participant age, and analysis by gender revealed no significant differences in proficiency between males ($N = 35$) and females ($N = 37$); therefore, age and gender were not included in the ERP correlational analyses. As results from the between-groups analyses provided specific hypotheses concerning the direction of the effects,

all significance levels reported are one-tailed unless otherwise specified.

Correlational analyses also revealed possible environmental factors contributing to proficiency differences in adult monolingual native speakers. Proficiency correlated with the amount participants reported reading as children ($r = .234, p < .05$), and there was a nearly significant correlation with the frequency participants reported being read to when children ($r = .190, p = .055$), whereas there was a negative correlation with the amount of time participants reported playing video games as children ($r = -.334, p < .005$). The amount of time participants reported reading as children also correlated positively with the amount of time participants reported reading as adults ($r = .450, p < .0001$), as did the frequency participants reported being read to as children ($r = .298, p < .01$). All four self-report measures of childhood environment correlated significantly with SES: amount participants reported reading ($r = .378, p < .005$), frequency participants reported being read to ($r = .538, p < .0001$), watching television ($r = -.265, p < .05$), and playing video games as children ($r = -.319, p < .005$).

Although proficiency did not correlate with the amount of time participants reported reading as adults, there was a significant negative correlation between proficiency and the amount of time participants reported watching television as adults ($r = -.429, p < .0001$). In addition, a self-rating measure in which participants were asked to rate their language skills compared with other adult native speakers on a five-point scale correlated significantly with both SES ($r = .317, p < .005$) and proficiency ($r = .437, p < .0001$).

ERP Results

Overall, results from the correlational analyses supported the findings from the between-groups analyses and provided converging evidence from a complementary analytical approach for effects of proficiency on neural organization for syntactic processing. These analyses revealed the strongest effects of proficiency in later time windows over both anterior and posterior electrode sites. Importantly, these effects of proficiency were found to be independent of other confounding variables, as partial correlations were used to control for the effects of SES, WM span, and education level. In addition to proficiency effects, these analyses also revealed an effect of SES on the amplitude of the ELAN.

Anterior Negativity

100- to 300-msec TW. Although no zero-order correlations reached significance in this time window, there was a near-significant partial correlation with proficiency and average difference amplitude over right anterior medial sites ($r = .194, p = .052$). Consistent with the results from the between-groups analyses, this analysis revealed that LP participants showed an increased negative response over these sites.

300- to 700-msec TW. Significant zero-order correlations were found between proficiency and average difference amplitude over both left anterior ($r = .365, p < .005$) and right anterior ($r = .334, p < .005$) sites (Figure 3). Partial correlations across these sites were also significant
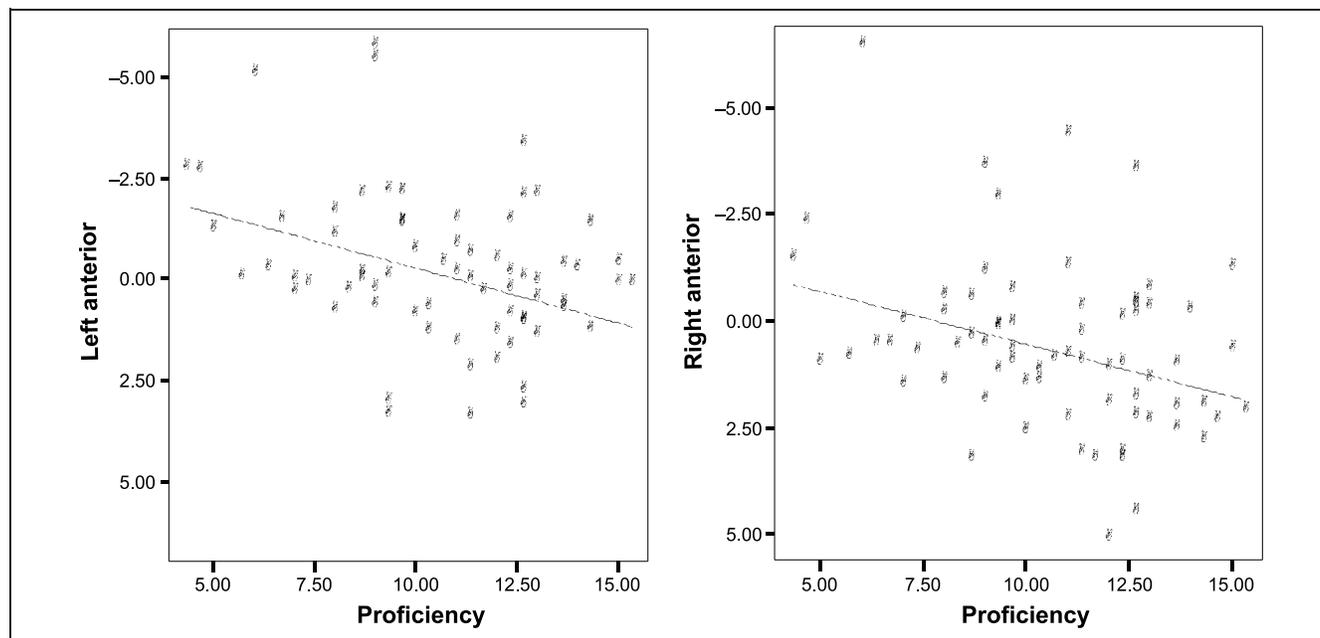

Figure 3. Correlation between average difference amplitude (violation − canonical, in μV) over left anterior and right anterior sites and proficiency in the 300- to 700-msec time window.

(left anterior: $r = .406$, $p < .0001$; right anterior: $r = .276$, $p < .05$), as were partial correlations across left anterior lateral ($r = .337$, $p < .005$), left anterior medial ($r = .430$, $p < .0001$), and right anterior medial ($r = .325$, $p < .005$) sites. The relationship was weakest across right anterior lateral sites, where the partial correlation tended toward significance ($r = .184$, $p = .065$). These correlations revealed that LP participants showed a more negative response whereas HP participants showed a more positive response across this time window, consistent with the results from the between-groups analyses.

700- to 1200-msec TW. Significant zero-order correlations were found between proficiency and average difference amplitude over both left anterior ($r = .203$, $p < .05$) and right anterior ($r = .230$, $p < .05$) sites, revealing that LP participants showed a more negative response across this time window. Partial correlations across these sites only approached significance (left anterior: $r = .193$, $p = .057$; right anterior: $r = .177$, $p = .076$).

Posterior Positivity (P600)

As shown in Figure 4, a significant zero-order correlation was found in the 300- to 1000-msec TW across posterior sites ($r = .279$, $p < .01$). A significant partial correlation was also observed across these sites ($r = .274$, $p < .05$). Consistent with the results from the between-groups analyses, these correlations revealed that HP participants showed a larger P600 response. Additional analyses revealed a relationship between the size of the P600 across posterior sites and the presence of a positivity across anterior sites in the 300- to 700-msec time window: There were significant positive zero-order correlations between
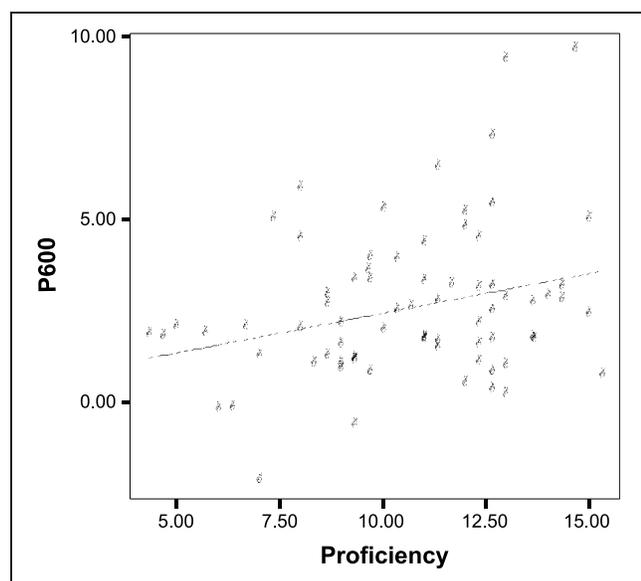

Figure 4. Correlation between average difference amplitude (violation − canonical, in μV) over posterior sites and proficiency in the 300- to 1000-msec time window (P600).

the posterior P600 and the average difference amplitude between 300 and 700 msec across both left ($r = .448$, $p < .0001$) and right ($r = .420$, $p < .0001$) anterior sites. This relationship was stronger over medial sites in both left (medial: $r = .505$, $p < .0001$; lateral: $r = .334$, $p < .001$) and right (medial: $r = .506$, $p < .0001$; lateral: $r = .263$, $p < .05$) hemispheres.

Socioeconomic Status

In addition to effects of proficiency, exploratory analyses using the correlational approach revealed significant relationships between SES and neural organization for syntactic processing, specific to left anterior sites. Although a zero-order correlation across left anterior sites in the 100- to 300-msec time window only approached significance ($r = -.176$, $p = .069$), a partial correlation across these sites controlling for proficiency, WM, and education level was significant ($r = -.218$, $p < .05$), revealing that participants from higher SES backgrounds showed a larger amplitude negativity to syntactic violations over left anterior sites. This relationship was slightly stronger over left anterior lateral sites (partial correlation: $r = -.223$, $p < .05$) than over left anterior medial sites (partial correlation: $r = -.197$, $p = .052$).

To investigate the contributions of factors related to self-reported childhood experience, we examined the relationship between left anterior average difference amplitude and SES while controlling for the amount participants reported reading, being read to, watching television, and playing video games as children. These factors were found to moderate the relationship between the neural response to syntactic violations and SES, as the partial correlation between average difference amplitude over left anterior sites and SES was reduced over both the 100- to 300-msec ($r = -.081$, *ns*) and the 300- to 700-msec ($r = -.021$, *ns*) time windows. None of these factors were found to moderate any of the correlations with proficiency described above.

DISCUSSION

In this study, ERPs elicited by phrase structure violations were examined as native speakers of English listened to simple sentences in English. Participants were recruited from a wide spectrum of society and given standardized measures of English language proficiency, and two types of analysis using complementary approaches were performed. In the between groups analyses, participants were divided on the basis of standardized proficiency scores into LP and HP groups. Analyses revealed differences in brain organization between the two proficiency groups, with HP participants showing an early anterior negativity that was more restricted both spatially and temporally and a larger and more widely distributed positivity to violations in English. In the correlational analyses, we explored the relationship between proficiency and neural

organization for syntactic processing across a wide spectrum of proficiency scores by examining the degree to which individual proficiency scores correlated with individual neural responses to syntactic violations in regions and time windows identified in the between-groups analyses. This approach also used partial correlation analyses to control for possible confounding variables. These correlational analyses provided converging evidence for the effects of proficiency discovered in the between-groups analyses, confirming that differences in proficiency predict neural indices of syntactic processing indexed by both anterior negativity and posterior positivity components. In addition, these analyses revealed links with SES that were specific to left anterior sites. Below we discuss possible interpretations of these results and their implications for theories of sentence processing and future directions for research and comment on the potential of research into proficiency differences for enriching our knowledge about language processing.

Anterior Negativity

Although the component referred to as the LAN is so named because it most often has been reported to display a distribution that is maximal over left anterior electrode sites (e.g., Gunter et al., 1999; Hahne & Friederici, 1999; Coulson, King, & Kutas, 1998b; Münte et al., 1993; Neville et al., 1991), this is not always the case. Several studies have reported an anterior negativity that is more bilateral in distribution (e.g., Yamada & Neville, 2007; Rossi et al., 2006; Ye, Luo, Friederici, & Zhou, 2006; Friederici & Meyer, 2004; Frisch, Hahne, & Friederici, 2004; Hagoort et al., 2003; Hahne & Friederici, 1999, 2002; Hahne, 2001; Hahne & Jescheniak, 2001; Friederici & Frisch, 2000; Münte et al., 1997; Friederici et al., 1993). To date, no theory of language processing has sought to address the functional significance of these differences in distribution, although the question has been identified as an important one for future research (Hahne & Friederici, 2002).

Although the differences in distribution of the anterior negativity effect have sometimes been attributed to subtle differences in the stimuli used (Hagoort et al., 2003), in other cases a bilateral negativity has been found using the same stimuli and experimental methods as in other studies that did find a left lateralized anterior negativity (Hahne & Friederici, 2002). This raises the hypothesis that proficiency differences in the participants tested may have at least contributed to the observed differences in distribution. The results of the current study support this hypothesis. In the between-groups analyses, participants who scored higher on standardized tests of English proficiency showed a more focal, left-lateralized early anterior negativity to straightforward phrase structure violations in English, whereas participants who scored lower showed an effect that was more widespread both spatially and temporally. This between-groups spatial difference was reflected in an increased negativity over right anterior medial sites

in the 100- to 300-msec time window in LP participants, a finding that was supported by a correlation between proficiency and average difference amplitude over right anterior medial sites in this time window.

The anterior negativity in this study began early, around 100 msec, and was elicited by insertion phrase structure violations. Such early components elicited by word category violations have been interpreted by some researchers to reflect early and automatic processes in which a word is integrated into the phrase structure of the preceding sentence fragment (Friederici, 2002). Although other theories dispute the automaticity of these processes with regard to the influence of contextual information (van den Brink & Hagoort, 2004), both theories are consistent in their view that early anterior negative components reflect processes that make immediate use of incoming input to guide on-line parsing. Given these interpretations, our results suggest that such early and immediate sentence parsing processes may operate differently, or be used differently, in adult monolingual native speakers who differ in their linguistic proficiency when processing their native language.

A preliminary, testable functional explanation for these differences is that LP participants recruited additional resources related to early processing to parse straightforward phrase structure violations in simple sentences in their native language. Given the overall similarity of the effect reported here to those previously reported for monolinguals and the spatial and temporal differences between groups, it seems likely that these differences reflect the recruitment of additional resources in similar systems. Although the early effect is larger over right anterior medial sites in the LP group, there is still a small negative deflection in the same location in the HP group. Thus, it appears that these differences may reflect the less efficient use in LP participants of neural systems similar to those used by HP participants. Although in both groups these systems make immediate use of incoming input to guide syntactic parsing, in HP participants these systems are highly focal and short in duration. This interpretation is consistent with some ERP evidence from bilinguals. Some studies have failed to find an anterior negativity effect to phrase structure violations in low proficiency late bilinguals (Hahne, 2001; Hahne & Friederici, 2001), suggesting that a certain level of proficiency is necessary to recruit the neural mechanisms indexed by the anterior negativity for on-line syntactic processing. Other evidence suggests that when these resources are recruited in late bilinguals, the distribution is related to proficiency, as the anterior negativity to phrase structure violations has been reported to be more bilateral and widespread in distribution with increases in age of immersion and decreases in English proficiency (e.g., Rossi et al., 2006; Weber-Fox & Neville, 1996). Evidence from neuroimaging studies of sentence processing also supports this interpretation. Activation in peri-sylvian language areas of the left hemisphere (e.g., Caplan et al., 2002; Caplan, Alpert, & Waters, 1999; Stromswold, Caplan, Alpert,

& Rauch, 1996) and bilaterally (Just, Carpenter, Keller, Eddy, & Thulborn, 1996) has been found to vary as a function of syntactic complexity and, presumably, the amount of resources necessary to process more complex syntactic structures.

The between-groups analyses also revealed that the anterior negativity effect was more focal temporally in HP participants, whereas the effect was temporally more extended in LP participants. This was supported by the correlational analyses, which revealed that LP correlated with increased negativity in both the 300- to 700-msec and the 700- to 1200-msec time windows. ERP studies of language development have reported a pattern in which language-related ERP effects become more focal spatially and temporally with increases in age and/or language ability (e.g., Hahne, Eckstein, & Friederici, 2004; Adamson-Harris et al., 2000; Mills et al., 1993; Neville et al., 1993). Although caution is necessary when comparing studies of children and adults, this raises the hypothesis that individual differences in the development of neural systems important for some aspects of language processing may endure into adulthood. This hypothesis will be discussed more below with relation to the correlational results with SES.

The finding that the anterior negativity effect extended to the 700- to 1200-msec time window in the LP group was somewhat unexpected. Previous studies have reported an N400-like "wrap-up" effect that has been observed to the final word in sentences judged to be unacceptable because of either a semantic or a syntactic violation (e.g., Hagoort & Brown, 1999; Hagoort et al., 1993; Osterhout & Holcomb, 1992, 1993). The late negativity observed in this study could reflect similar processes engaged when participants encountered the final word in the sentence. Although the distribution of this "wrap-up" effect is usually more widespread and central than the distribution of the late negativity observed here, the relatively late position of the violation creates a temporal and spatial overlap with the posterior positivity, which makes a definitive interpretation of this effect difficult based solely on this evidence. However, additional evidence from a study using ERP and fMRI data gathered from the same participants in this paradigm allows for a degree of clarification regarding the interpretation of this component (Pakulak, Dow, & Neville, 2009; Pakulak, 2008). That analysis provides evidence that one of the neural generators of this component is anatomically close to the neural generator of the anterior negativity in the 100- to 300-msec time window, suggesting that the negativity over anterior sites in the later time window indexes processes similar to the negativity in the earlier time window.

Posterior Positivity (P600)

We found a typical biphasic response in which the anterior negativity was followed by a later, posterior positivity that is consistent in latency and distribution with the component typically referred to as the P600. The P600 has been interpreted as an index of more controlled processes related to syntactic repair and revision in the face of a violation (Friederici, 2002) or to the cost of syntactic integration (Kaan et al., 2000) and more recently as an index of the amount of competition between alternative options as the parser attempts to unify linguistic elements in the comprehension of an utterance (Hagoort, 2003). As with the anterior negativity, the between-groups analyses revealed differences in the P600 effect between groups: the P600 was larger in amplitude in the HP group compared with the LP group and was more widespread in distribution, extending to anterior medial sites in the HP group. These findings were confirmed by the correlational analyses, in which proficiency positively correlated with average difference amplitude over anterior sites in the 300- to 700-msec time window and over posterior sites in the 300- to 1000-msec time window.

A more frontally distributed P600 has been hypothesized to reflect processing difficulties associated with revision when the parser encounters grammatical but nonpreferred continuations in syntactically complex and/or ambiguous sentences, whereas a P600 with a more posterior distribution has been hypothesized to reflect a parsing failure and/or resulting repair processes when the parser encounters a grammatical violation (Friederici et al., 2002; Hagoort & Brown, 2000). Given these past findings concerning the distribution of the P600, it is unclear why straightforward, unambiguous violations would elicit a more frontally distributed P600 in the HP group. However, the correlational analyses revealed strong correlations between the positivity across anterior sites and the positivity across posterior sites across all 72 participants, suggesting that the frontally distributed P600 may reflect part of a more widespread effect indexing similar as opposed to separate processes. Although both groups showed a posterior P600 to phrase structure violations, this effect was larger in HP participants and positively correlated with proficiency across all participants. The size of the P600 has been shown to be reduced when participants do not perform a grammaticality judgment task (Hahne & Friederici, 2002), which suggests that this difference in amplitude may reflect greater engagement of processes related to revision and repair in the context of the grammaticality judgment task on the part of the HP participants. However, as there was no task manipulation that explicitly required repair processes this interpretation is necessarily tentative and calls for more research.

Overall, the strength of the correlations between average difference amplitude and proficiency reveals that the strongest effects of proficiency were found in the 300- to 700-msec time window over anterior sites and in the 300- to 1000-msec time window over posterior sites. Although LP is associated with an extended negativity or weak positivity over anterior sites and a smaller P600 across posterior sites, HP is associated with a robust and widespread P600 extending to anterior sites. While the functional interpretation of the P600 is still being clarified, it is clear that the process or processes indexed by this component

are more engaged in participants with HP. Be they related to repair and/or reanalysis in the face of a violation, syntactic integration in general, or competition between alternatives in the unification of linguistic elements for comprehension, activation of processes that become engaged when the parser encounters difficulty is likely to be associated with better performance across a variety of tasks involving syntactic processing, and the results from this study show that this is indeed the case.

Optimal Neural Organization for Syntactic Processing

Overall, the results presented here present a profile of neural organization for syntactic processing that is predicted by HP. Reflected in this organization is an interaction between processes considered to be more automatic and those hypothesized to be more controlled. It is reasonable to propose that the response associated with HP represents the most efficient allocation of these processes: A more focal early anterior negativity, which indexes more efficient detection of word category violations, "frees up" more controlled resources involved with repair and reanalysis reflected in the widespread P600, and it is this allocation that represents an optimal neural organization for syntactic processing in monolinguals. Although it is not possible to draw a definitive causal link between these processes, the relative timing makes it more likely that more efficient earlier processes would free up resources reflected in later processes and not the other way around. A different picture emerges with LP: Less efficient automatic processes involved in the detection of word category violations, reflected in more widespread distribution spatially and temporally, are followed by reduced recruitment of more controlled processes. Here, again given the relative timing, it is likely that the less efficient nature of these early processes does not allow for the recruitment of later processes in LP individuals to the same degree as in HP individuals.

Other Possible Contributing Factors

The group differences in syntactic processing found in this study have been discussed in terms of English language proficiency, and the correlational analyses allowed for the control for other possible mediating factors. Still, it is possible that other factors contributed to the results.

Although in theory one possibility is that the pattern of results is due to differences in dialect, this is unlikely to explain the differences found. The experimental materials used were chosen to minimize any effects of dialect differences: The sentences used in the ERP paradigm were all simple, single-clause sentences created for a paradigm that was also used to investigate syntactic processing in 36 month-olds and the violations used were insertion phrase structure violations that are syntactic violations in any known dialect of English. All of the participants were native speakers of American English who came from the Eugene, Oregon area.

Another possibility is that individual resource limitations not explicitly controlled for are contributing to results found. One possibility is general intelligence. As our goal was to more completely characterize language proficiency while gathering all data in a single session, we were unable to include a direct assessment of intelligence. However, there is considerable evidence that WM correlates with intelligence (e.g., Conway, Cowan, Bunting, Therriault, & Minkoff, 2002), and the correlational analyses revealed that the results with regard to proficiency were not significantly affected by WM. Still, it is possible that differences in general intelligence contributed to our findings, and the relationship between general intelligence and brain organization for language is an important consideration in future research. Another factor that may have affected our results is attention. Although we were unable to control for individual differences in the several types of attention, such as executive function and sustained endogenous attention, which may influence performance in experimental paradigms such as ours, several facts suggest that attention had little or no effect on our results. The behavioral measures were given in a small, enclosed room one-on-one with the lead author, a setting specifically designed to minimize differences in attention, and all participants performed the tasks in a similar time frame. In the between-groups analyses, all participants attended to the stimuli well enough to answer more than 84% of the probe questions accurately and score above 84% on the grammaticality judgment task, and only correct responses were used in the ERP analyses. As discussed above, the pattern of ERP results and the modulation of ERP components reported are consistent with results from other populations (e.g., bilinguals). This pattern of results suggests that domain-general differences in attention are unlikely to have produced the specific pattern of results observed. More research is certainly needed into the interplay between WM, attention, intelligence, and language proficiency. Still, our results suggest that there exist proficiency differences in on-line syntactic processing that are independent of certain resource limitations, a finding that calls for further study.

Socioeconomic Status

This study also examined the relationship between linguistic proficiency and neural organization for syntactic processing in adults and the SES environment in which they were raised. In both cases, significant relationships were found that raise important hypotheses for future research.

In the correlational analyses of 72 participants, self-reported childhood SES correlated significantly with adult linguistic proficiency as assessed by standardized measures. This is agreement with a large literature documenting profound effects of SES on language in children (e.g., Noble, McCandliss, & Farah, 2007; Noble, Norman, & Farah, 2005;

Hoff, 2003; Hoff, Laursen, & Tardif, 2002; Huttenlocher, Vasilyeva, Cymerman, & Levine, 2002; Dollaghan et al., 1999; Hart & Risley, 1995) and raises the hypothesis that such differences endure into adulthood. Although these analyses are correlational and therefore cannot make any causal inferences or rule out genetic or epigenetic factors, additional evidence supports this hypothesis. Several self-reported measures of childhood environment—amount of time spent reading, being read to, watching television, and playing video games—correlated significantly with childhood SES, and there were relationships between proficiency and all of these measures but one. Of particular relevance is that the two measures of childhood reading showed the strongest correlations with SES, and both showed a positive relationship with adult proficiency. This is consistent with evidence that time spent reading or reading with an adult can have a positive effect on language development (Payne, Whitehurst, & Angell, 1994; Scarborough & Dobrich, 1994). Other evidence suggests that there are differences in the speech mothers use when reading with their children, such as using more utterances per unit of time, utterances with greater structural complexity, and a larger vocabulary, and that these speech differences can affect language development (Hoff, 2006; Hoff-Ginsberg, 1991). In addition, there is evidence that interventions which specifically seek to promote parent-child reading can positively affect vocabulary development (Sharif, Reiber, & Ozuah, 2002; Mendelsohn et al., 2001). Although caution is necessary, evidence for some specificity in the relationship between childhood environmental factors and adult proficiency raises the hypothesis that some effects of childhood environment related to SES may have enduring effects on language proficiency. Future research that specifically addresses causal relationships with the use of targeted interventions and that specifically addresses the role of other factors in the relationship between childhood SES and language development will provide important evidence bearing on this hypothesis.

We also observed a correlation between childhood SES and neural response to syntactic violations, such that participants from higher SES backgrounds showed a larger negative response to violations than participants from lower SES backgrounds. This effect was specific to left anterior sites in both the 100- to 300-msec and the 300- to 700-msec time windows, and the results of the partial correlation analysis revealed that this effect was independent of proficiency as well as WM and education level. However, given the results discussed above with regard to SES and proficiency, the interpretation that the relationship between SES and LAN amplitude is independent of proficiency should be treated with caution. It is possible that this relationship is moderated to some degree by aspects of linguistic proficiency that were not reflected by the proficiency measures used, although further clarification is beyond the scope of this study. Still, these results raise the additional hypothesis that differences related to childhood SES environment that can affect language development may also have effects on

neural organization for language that endure into adulthood. An alternate hypothesis is that these differences in the neural response of left anterior sites are the result of genetic differences that covary with our measurement of childhood SES. However, this relationship disappeared when childhood environmental factors—amount of time spent reading, being read to, watching television, and playing video games—were controlled for. This provides evidence that our measure of childhood SES is a mediating variable for specific aspects of childhood environment and strengthens the hypothesis that experiential factors may have effects on neural organization for syntactic processing that endure into adulthood. Although necessarily preliminary and cautious, the hypothesis that environmental effects of SES that impact language development may also have a lasting impact on neural organization for syntactic processing provides an intriguing direction for future research.

The results relating to SES discussed above were the result of correlational analyses using data collected from 72 adults from a wide spectrum of society and a wide range of childhood SES backgrounds. Reviews of results from studies of the effects of SES on language development in children suggest that the magnitude of differences related to SES depends on the range of SES in the sample studied (e.g., Hoff, 2006). Overall, this suggests that to obtain a more complete picture of neural organization for syntactic processing or of neural organization more generally, it will be important to study samples from a wider and more diverse spectrum of society.

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