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Conflict Resolution in Sentence Processing by Bilinguals

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Abstract

The present study pursues findings from earlier behavioral research with children showing the superior ability of bilinguals to make grammaticality judgments in the context of misleading semantic information. The advantage in this task was attributed to the greater executive control of bilinguals, but this impact on linguistic processing has not been demonstrated in adults. Here, we recorded event-related potentials in young adults who were either English monolinguals or bilinguals as they performed two different language judgment tasks. In the acceptability task, participants indicated whether or not the sentence contained an error in either grammar or meaning; in the grammaticality task, participants indicated only whether the sentence contained an error in grammar, in spite of possible conflicting information from meaning. In both groups, sentence violations generated N400 and P600 waves. In the acceptability task, bilinguals were less accurate than monolinguals, but in the grammaticality task which requires more executive control, bilingual and monolingual groups showed a comparable level of accuracy. Importantly, bilinguals generated smaller P600 amplitude and a more bilateral distribution of activation than monolinguals in the grammaticality task requiring more executive control. Our results show that bilinguals use their enhanced executive control for linguistic processing involving conflict in spite of no apparent advantage in linguistic processing under simpler conditions.

Keywords

ERP; language; Bilingualism; Control; Executive functions; Syntax; Semantic; N400; P600

Studying judgments of sentence acceptability is a commonly-used method for understanding elements of syntactic and semantic processing. In a number of studies, mostly investigating children, this technique has been used to reveal differences between monolingual and bilingual participants (Bialystok, 1986, 1988). Language processing, however, must ultimately be explained in the context of the cognitive system with which it is interconnected. The purpose

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of the present study was to examine the differences found in semantic and syntactic processing of sentences for monolingual and bilingual adults under conditions demanding different levels of executive control by investigating the neural correlates of these processes.

In two studies, Galambos and colleagues found that bilingual children outperformed monolinguals in both judging and correcting syntactically incorrect sentences (Galambos & Hakuta, 1988; Galambos & Goldin-Meadow, 1990). Bialystok (1986, 1988, Bialystok & Majumder, 1998) created a paradigm in which the sentences to be judged contained either syntactic errors, semantic anomalies, or both but children were instructed to judge only the syntax. This manipulation created conditions that involved different levels of attentional control as well as grammatical knowledge; when one dimension was correct and the other was incorrect, it was necessary to attend only to the grammar and ignore the meaning. Since meaning is more salient than grammatical form, especially for children, it is effortful to ignore an anomalous meaning and respond appropriately to a grammatically intact sentence. Children between 5- and 9-year-olds in both language groups were equivalent in judging the syntax when the meaning was intact (i.e., rejecting sentences such as “Apples growed on trees”), but bilinguals were better than monolinguals at agreeing that the syntax was correct when the meaning was anomalous (i.e., accepting sentences such as “Apples grow on noses”). These results were replicated by Ricciardelli (1992) with Italian-English bilinguals and Cromdal (1999) with Swedish-English bilinguals.

The finding that bilingual children were better able to control attention to syntax in the context of conflicting semantic information led to a series of studies that demonstrated that this increased control of attention extended to nonverbal tasks in both children (Bialystok & Majumder, 1998; Carlson & Meltzoff, 2008; Goetz, 2003) and adults bilinguals (Bialystok et al., 2005; Costa et al., 2008; Colzato et al., 2008; McLeay, 2003). The interpretation of these advantages was that domain-general executive function mechanisms are used to control attention to the target language (Green, 1998) to resolve the conflict that comes from both languages being constantly active in bilinguals (Schwartz and Kroll, 2006; Spivey & Marian, 1999; Van Heuven, Dijkstra, & Grainger, 1998). This constant exercise of the executive function for language processing improves those functions broadly, enhancing performance in nonverbal tasks as well. However, support for these claims requires demonstrating the role of executive control in syntactic and semantic processing and demonstrating a difference between the way in which monolinguals and bilinguals resolve linguistic conflict.

Scalp recordings of event-related brain potentials (ERPs) provide a means to assess semantic and syntactic processing and have been shown to be sensitive to linguistic expertise and bilingualism (Moreno et al., in press). Four ERP components are particularly relevant to the present study. The N400 component is a centro-parietally distributed negativity that is emitted in response to words which do not semantically fit into their semantic context (Kutas & Hillyard, 1980). Its amplitude varies with ease of contextual (semantic) integration: the more difficult it is to integrate the word with the representation of the ongoing context, the larger the N400 amplitude with all other factors, such as frequency, repetition, imageability, and word class held constant (for a review, see Kutas & Federmeier, 2000). The N400 congruity effect is delayed in bilinguals for their less-dominant language (L2) and appears to be left lateralized (Ardal et al., 1990; Proverbio et al., 2002, Weber-Fox & Neville, 1996). In a recent study, Moreno and Kutas (2005) found that the latency of semantic integration effects in Spanish-English bilinguals reflected in N400 was attributable to both age of exposure to the L2 and language proficiency. However, proficiency does not need to be very high for the N400 to appear: McLaughlin and Osterhout (2004) showed a strong N400 peak for semantic anomalies after only one month of instruction in a second language. These results indicate that semantic processing is involved at the earliest stage of language proficiency.

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The remaining three ERP waves are thought to index syntactic processes: Early Left Anterior Negativity (ELAN, ~200 ms post-stimulus), Left Anterior Negativity (LAN), ~400 ms post-stimulus), and P600 (a centro-parietal positive wave at ~ 600 ms post-stimulus). The ELAN has been observed for phrase structure violations or word category violations (Friederici, Pfeifer & Hahne, 1993; Gunter, Friederici & Hahne, 1999; Hahne & Friederici, 1999; Neville, Nicol, Barss, Forster & Garrett, 1991) and during the processing of grammatically-based closed class words as opposed to semantically-based open class words (Brown, Hagoort & ter Keurs, 1999; Neville, Mills and Lawson, 1992; Nobre and McCarthy, 1994). This component may reflect automatic processes as it is not influenced by the proportion of correct and incorrect sentences or a differential attentional focus introduced via task instructions (Hahne & Friederici, 1999, 2000). Moreover, it has been observed in monolinguals but not in bilinguals (Hahne & Friederici, 2001: Age of acquisition (AOA): 21 and proficiency (P): 3.5 on a six-point scale; Weber-Fox & Neville, 1996: AOA: several AOA:1–3, 4–6, 7–10, 11–13, after 16 and P: the younger groups were self-rated their proficiency higher for English than Chinese: 1–3, 4–6, 7–10, the 11–13 group self-rated their proficiency as equivalent in English and Chinese and the last group self rated their English proficiency lower than their Chinese Proficiency).

The LAN has been also shown to be elicited by a variety of syntactic violations, such as morphological agreement violations (Coulson, King & Kutas, 1998; Gunter, Stowe & Mulder, 1997; Munte, Matzke & Johannes, 1997; Osterhout & Mobley, 1995; Penke, Weyerts, Gross, Zander, Munte & Clahsen, 1997). Its latency varies across studies but it has mostly been reported in the range of 200 to 600 ms after target onset.

Finally, the P600 is evoked by syntactic violations (Friederici et al., 1993; Osterhout & Holcomb, 1992; Neville et al., 1991), noncanonical or less preferred structures (Osterhout, Holcomb, & Swinney, 1994), or syntactically complex structures (Kaan, Harris, Gibson, & Holcomb, 2000). It is thought to reflect processes of reanalysis and syntactic repair (Friederici, 2002; Osterhout et al., 1994; Osterhout & Holcomb, 1992).

Previous ERP studies have observed differential ERP patterns for processing syntactic violations in English as a function of whether English was the L1 or L2. For instance, Weber-Fox and Neville (1996) found that when the L2 (English) was learned after the age of 3 years, the ELAN and the LAN were not observed, and after the age of acquisition of 16 years, no P600 was present. Thus, the appearance of distinctive waveforms may be related to the age at which the language was acquired, or possibly the length of time the individual has been using that language. Proverbio et al. (2002) reported that although the P600 response to syntactic errors was larger over the left hemisphere in monolinguals, it was equivalent in both hemispheres for bilinguals, suggesting that brain activity for language processing is more distributed across hemisphere for bilinguals than for monolinguals. However, a recent study by Kotz et al. (2007) revealed comparable P600 waves evoked by syntactic violation in both bilinguals and monolinguals. Thus, there remains uncertainty about the factors that determine whether monolinguals and bilinguals differ in these respects (for a review, see Moreno et al., in press).

To more clearly isolate the semantic and syntactic components of these processes, Hahne and Friederici (2001) compared bilinguals (L2 learners) and monolinguals on an auditory sentence judgment task that contained four sentence types that were similar to those used in the study by Bialystok (1986): correct, syntactically incorrect but meaningful, semantically anomalous but grammatical, and syntactically and semantically incorrect. Unlike the task used by Bialystok (1986), however, participants judged whether the sentence was acceptable or not using any criteria. The main differences between groups were a greater positivity to the correct sentences in L2 learners than in native listeners, an effect thought to reflect greater difficulty in syntactic integration, and a late right anterior-central negativity to the ungrammatical anomalous sentences observed only in L2 learners. In a related experiment, Hahne (2001) compared monolinguals with bilinguals who had learned German after the age of 10. These bilinguals were more proficient than those in the previous study. However, the N400 wave for correct sentences was delayed by approximately 100 ms in the bilingual group, suggesting that semantic integration was more difficult for the bilinguals than for the monolinguals. Syntactic processing was also different: bilinguals showed a slight delay in the P600 and monolinguals produced an early anterior negativity that did not appear in the bilinguals. Together these two studies show functional differences between monolinguals and bilinguals in late linguistic processes.

To summarize, previous research has shown N400 latency shift for bilinguals relative to monolinguals (Moreno and Kutas, 2005) but syntactic processing components (ELAN, LAN and P600) have not been studied as extensively as those associated with semantic processing. Syntactic violations evoked ELAN and LAN components in monolinguals but not in bilinguals (Hahne & Friederici, 2001; Weber-Fox & Neville, 1996). For P600, some studies showed an amplitude difference with larger amplitude for bilinguals than monolinguals (Hahne & Friederici, 2001), while others showed a latency difference with a longer delay for bilinguals than monolinguals (Hahne, 2001), or no difference between groups (Kotz et al., 2007; for a review, see Moreno et al., 2008). None of these studies, however, manipulated the degree of executive control required because the conflict between syntactic and semantic values was not relevant for performance.

In the task used Bialystok and colleagues with children, the instructions were to judge the syntactic acceptability of the sentence and to ignore the meaning. In these studies, bilinguals were more accurate than monolinguals in judging grammaticality when there was conflict from semantic information but there was no difference between children in simple judgments of grammaticality in the absence of such conflict (review in Bialystok, 2001). Therefore, an explanation of how bilingualism affects syntactic and semantic processing requires that the cognitive and attentional demands in these judgment tasks are understood as well. In the present study, we compared the standard version of an acceptability judgment task with the version used in the earlier research with children (Bialystok, 1986) that includes demands for executive control to resolve conflict between sentence form and sentence meaning. We used sentences from Osterhout and Nicol (1999) which produce qualitatively distinct ERP responses to semantic and syntactic violations, namely, the N400 and P600 effects, respectively.

The sentences were presented in two instructional conditions. In the acceptability task, participants were told to respond "yes" to sentences that were okay and "no" if there was something wrong. This is the standard instruction for this type of research. In the grammaticality task, participants were told to judge only the syntax, irrespective of the meaning. Thus, the sentence "The sea lions can *edit* on the beach all day" would produce "no" for the acceptability task but "yes" for the grammaticality task; the sentence "The sea lions can *basking* on the beach all day" would produce "no" for both tasks. We expected a modulation of the syntactic ERP components in response to this change in the instruction.

Our first hypothesis was that bilinguals would demonstrate overall lower performance on the behavioral measures than monolinguals, reflecting their lower levels of English proficiency (Portocarrero et al., 2007). Second, we expected that the ERPs would reveal the typical waves for semantic (N400) and syntactic (P600) violations for all participants. However, because N400 latency is influenced by language proficiency (Weber-Fox & Neville, 1996), there should be longer N400 latency for bilinguals than monolinguals in both tasks. Third, following previous research, we expected to observe ELAN and LAN waves for monolinguals but not for bilinguals (Hahne & Friederici, 2001; Weber-Fox & Neville, 1996). Fourth, the grammaticality task requires a higher degree of executive control to focus on the syntax in the context of conflicting value for meaning, so we expected that the processing demands of the task should be handled more efficiently by the bilinguals. This effect would be demonstrated by reduced amplitude for the P600 wave in the grammaticality task. As the acceptability task is based on a global judgment, this task will not demand the same level of control processing so we hypothesized that there would be comparable syntactic brain processing in both groups (Kotz et al., 2007). Previous studies have reported amplitude diminution of late positive waves when less attentional control is involved (Moreno et al., 2008; Moreno & Besson, 2006; Klein et al., 1984) while others have found a decreased P600 effect in response to syntactic violations in low proficiency L2 learners compared to natives (Rossi et al., 2006). The difference in executive control involvement for the grammaticality and acceptability tasks will allow us to distinguish between the need for less executive control and the ability to detect syntactic violations. If bilinguals show a reduced P600 amplitude in both tasks, the interpretation is that they have lower proficiency; however if bilinguals show reduced P600 amplitude only in the grammaticality task, the interpretation is that they have better executive control. Finally, consistent with results reported by Proverbio (2002), we expected the topography of bilingual brain's electrical activity to be bilateral and for monolinguals to be left-lateralized.

Method

Participants

Sixteen English monolingual and sixteen bilingual university students between the ages of 18 and 33 years old were recruited. Data from two participants were discarded due to excessive ocular artifacts; data from two other volunteers were discarded as a result of very poor accuracy. The final sample was composed of 14 monolingual (mean age 23.6 ± 3.1 years; seven males; all right handed) and 14 bilingual (mean age 23.5 ± 4.5 years; two males; two left handed) adults. Supplementary statistical analyses were conducted to show that left-handed were similar to right-handed participants (see Result section). Monolingual participants were all born and raised in English speaking countries, either Canada or the United States. Bilingual participants were born in Canada (4), Russia (1), Romania (1) or Israel (8). The non-English language of the bilinguals included Hebrew (9), Russian (1), Romanian (1) and French (3). Eight bilinguals had some knowledge of a third language (average self-rated proficiency on 0–100% continuum was mean = 43.4). Bilingual participants immigrated to Canada at various ages in childhood (ages ranged from 1 to 15), except one participant who immigrated at 30 years old but reported having learned English at 8 years old. Twelve of the fourteen bilingual participants learned L2 before age 12 (mean= 6) and two participants were late learners, one 15-years old and the second at 14-years old (mean = 7.2). Only one bilingual reported to have English as a first language, but six bilinguals considered English as their dominant language. Their average dominant language proficiency self-ratings on a 0 – 100% scale (where 100% corresponded to native like proficiency) was higher (mean = 97.1) that for the non-dominant language (mean = 81.9).

The bilingual participants completed a test of receptive vocabulary knowledge in English; the 12 bilinguals for whom Hebrew or French was the other language also completed this test in that language (Standard PPVT English[1] score: 103; Hebrew score: 109; French score: 124). All participants filled out a language background questionnaire. On average, bilinguals spoke 26% English at home and 85% at work and heard 38% English at home and 89% at work.

[1]A one-way ANOVA by group (early vs late L2 learners) on English PPVT vocabulary scores showed no effect for age of learning English, *p* > .69.

All participants reported normal vision. Each individual provided informed consent in accordance with the guidelines established by the University of Toronto and Baycrest Centre for Geriatric Care.

Procedure

There were two testing sessions – one for psychological assessment lasting approximately 45 minutes and the second for ERP testing lasting approximately 1½ hours (including setup and practice). Participants were compensated monetarily for their time.

Behavioral tasks

The psychological assessment session consisted of a battery of tests including the Language and Social Background Questionnaire, Peabody Picture Vocabulary (PPVT) – III (Dunn & Dunn, 1997), Cattell Culture Fair intelligence (Cattell, 1957), and Corsi Block tests (as used in Fisher, 2001). The purpose of these assessments was to establish the comparability of participants across the groups on vocabulary (PPVT), intelligence (Cattell) and working memory (Corsi block test).

ERP Sentence Judgment Task

One-hundred-twenty sentence frames from Osterhout & Nicol (1999) were used to construct sentences that were correct, syntactically incorrect but meaningful, semantically anomalous but grammatical, or syntactically incorrect and semantically anomalous (see Table 1). This procedure allowed us to isolate the response to either a syntactic or semantic error in comparison to intact sentences. Sentences that contained both syntactic and semantic errors were considered filler sentences. Their purpose was to balance the number of correct and incorrect sentences and to complete the design. The ERPs from these sentences were not analyzed because the semantic and syntactic effects could not be unambiguously isolated. Thus, a correct sentence such as, “A new computer will *last* for many years” could be made syntactically incorrect, “A new computer will *lasting* for many years”, or semantically anomalous, “A new computer will *paint* for many years”. The syntactically incorrect version always involved a modal verb followed by a present participle (-*ing*) form of the verb (e.g., *will lasting, verb tense* violations). In the semantically anomalous version, the matrix verb appeared in the grammatically appropriate non-tensed form but introduced an unsuitable pairing of actions with agents (e.g., *computer-paint*). The unsuitability was usually due to a mismatch in animacy between the verb and the participant of the sentence, creating *selectional restriction* violations (Chomsky, 1965). The correct and semantically anomalous critical words were matched in frequency (semantically acceptable: mean = 96, semantically anomalous: mean = 70, $p > 0.2$; Kucera & Francis, 1967) and length in letters (semantically acceptable: mean = 4.94, semantically anomalous: mean = 4.52, $p > 0.3$). The properly tensed versions of each word were used to match for length and frequency. These materials were then used to create three stimulus lists. Each list contained 30 exemplars of each of the four experimental sentence types. Items were counterbalanced such that only one version of each sentence was presented on a given list. Thus, each participant saw a total of 120 sentences.

Procedures

Participants were seated in a comfortable chair in a soundproof room. Each trial consisted of a fixation cross for 500 ms followed by a sentence that was presented word-by-word, with each word appearing in the centre of the screen for 300 ms. A blank-screen interval of 350 ms separated words and this duration corresponded to the post-stimulus interval. Sentence-ending words appeared with a full stop. A 1450 ms blank-screen interval followed each sentence, after which a prompt appeared. In the acceptability task the prompt was: answer “yes” if the sentence is good and “no” if there is something wrong with the sentence, no matter what it is; acceptable sentences were defined as those that were semantically coherent and grammatically correct. In the grammaticality task, the prompt was: answer “yes” if the sentence is grammatically correct and “no” if it is grammatically incorrect, irrespective of the meaning. Participants indicated their response by pressing one of two buttons, which were counterbalanced for left and right positions across participants. Accuracy rates and ERPs were recorded. Reaction time was not recorded to avoid having the motor response (key press) override brain response to the critical word. Sentences were randomized between participants but the grammaticality task was always presented before the acceptability task.

ERP recording

Neuroelectric brain activity was digitized continuously from an array of 64 electrodes with a bandpass of 0.05–100 Hz and sampling rate of 500 Hz using NeuroScan Synamps2 (Compumedics, El Paso, TX, USA). During the recording, all electrodes were referenced to the Cz electrode but were re-referenced to an average reference for data analysis. Electrodes placed at the outer canthi and the superior and inferior orbit monitored vertical and horizontal eye movements.

All averages were computed using Brain Electrical Source Analysis (BESA, V.5.1.8) software. The analysis epoch included 200 ms of pre-stimulus activity and 1000 ms of post-stimulus activity. Amplitude thresholds were adjusted on a participant-by-participant basis. Thresholds ranged from 100 to 195 μV (average = 152 μV). ERPs were then averaged separately for each condition, stimulus type, and electrode site. Only correct trials were included in the averages.

For each participant, a set of ocular movements was obtained prior to and after the experiment (Picton et al., 2000). From this set, averaged eye movements were calculated for both lateral and vertical eye movements as well as for eye-blinks. A principal component analysis of these averaged recordings provided a set of components that best explained the eye movements. The scalp projections of these components were then subtracted from the experimental ERPs to minimize ocular contamination such as blinks, saccades, and lateral eye movements for each individual average. ERPs were then digitally low-pass filtered to attenuate frequencies above 20 Hz (zero phase; 24 dB/oct).

ERP analysis

Mean amplitudes were measured in selected latency windows based on prior research. For both tasks, ANOVAs were computed for central and lateral electrodes separately using group as a between-subjects factor and condition (correct, syntactically incorrect, and semantically anomalous) and electrodes (left central for N400: C1, Cz, CP1, CPz and parietal for P600: CP1, CPz, CP2, P1, Pz, P2) as within-subject factors for midline analyses. To assess potential hemispheric differences in processing sentence, we compared ERP amplitude recorded over the left (F7) and right (F8) frontal scalp region, and over the left (P3) and right (P4) parietal scalp region.

Semantically anomalous words generated a N400 wave that peaked between 300 and 600 ms after word onset and syntactically incorrect words generated an ELAN component that peaked between 100 and 250 ms, a LAN component that peaked between 200 and 600 ms, and a P600 wave that peaked between 400 and 1000 ms after word onset (peak amplitudes were quantified in this time window; hemispheric differences were quantified in a reduced latency window, from 500 to 650 ms). The amplitude and latency effect of group and condition on N400, ELAN, LAN and P600 waves were selected and quantified at the electrode sites described above in accordance with prior research.

Results

Background Control Measures

Table 2 shows group mean performance for the psychological tests. There were no significant group differences in age, education, or in performance on the Corsi and Cattell tasks (all $p > .35$). Only the English PPVT scores differed between the two groups, $F(1,27) = 5.36$, $p < .05$, with monolinguals obtaining higher scores than bilinguals.

Acceptability task

Behavioral performance—Monolinguals achieved higher accuracy scores than bilinguals, $F(1,26) = 4.7$, $p < .05$ (see Table 3). The main effect of condition was also significant, $F(2,52) = 14.6$, $p < .001$. Pairwise comparisons indicated that performance was higher for correct and syntactically incorrect sentences than for semantically anomalous ones ($p < .001$ in both cases), with no difference between correct and syntactically incorrect sentences ($p > .75$). The interaction between group and condition was not significant, $F(2,52) = 0.6$, $p > .55$.

Electrophysiological data—Comparing the correct and syntactically incorrect sentences, ELAN peak amplitude or latency showed no main effect and no interaction between group, condition, or hemisphere ($ps > .14$) (see Figure 1a). There was no main effect of group or condition for the 250–350 ms interval, ($ps>.41$), but the main effect of hemisphere approached significance, $F(1,26) = 3.8$, $p =.06$, with larger negative amplitudes over the left (−.57μV) than the right (−.14μV) hemisphere. The interaction between group, condition, and hemisphere was not significant ($p >.13$).

The N400 was quantified during the 350–480 ms interval. There was a main effect of condition, $F(1,26) = 5.3$, $p < .05$, revealing a larger N400 for semantically anomalous (−1.9μV) than for correct (−1.4μV) sentences (Figure 2a and 3a). The interaction between group and condition was not significant ($p > .17$).

Comparing the correct and syntactically incorrect sentences, the P600 difference waves[2] indicated no main effect of group ($p > .52$) (Figure 3a). For lateral electrodes (P3/P4: 500–650ms), the main effect of condition was significant, $F(1,26) = 5.21$, $p < .05$, revealing negative mean amplitudes for correct (−0.26μV) and positive mean amplitudes for syntactically incorrect (0.48μV) sentences. There were interactions between group and hemisphere, $F(1,26) = 4.42$, $p < .05$, and between group, condition, and hemisphere, $F(1,26) = 5.66$, $p < .05$. Separate ANOVAs for each group showed that for bilinguals, there was no main effect or interaction ($ps > .08$), but for monolinguals, there was a main effect of hemisphere, $F(1,13) = 8.33$, $p < .05$. Mean amplitudes were negative over the right (−0.43μV) and positive over the left (0.76μV) hemispheres (Figure 4a).

Grammaticality task

Behavioral performance—Accuracy levels were near ceiling in both groups (see Table 3). There was no reliable difference in participants' ability to judge the syntax of the sentence nor was the interaction between group and condition significant, both $p > .5$.

Electrophysiological data—Comparing the correct and syntactically incorrect sentences, ELAN peak amplitude indicated an interaction between condition and hemisphere, $F(1,26) = 7.8$, $p < .01$, revealing similar peak amplitudes in both hemispheres for correct sentences (right: −2.9μV and left: −3.1μV) but more negative peak amplitudes over the left (−3.4μV) than the

[2]We examined difference wave on the late positive component (P600) to avoid sensory effects elicited by the following word.

right (−2.4μV) hemispheres for syntactically incorrect sentences (see Figure 1b). Neither main effect nor interaction of group and hemisphere was significant (all $p > .53$).

In the 160–260 ms latency window, there was a main effect of condition, $F(1,26) = 15.42$, $p < .01$, showing greater positivity for semantically anomalous (0.9μV) than for correct (0.22μV) sentences. The interaction between group and condition was also significant, $F(1,26) = 14.1$, $p < .01$ (see Figure 5). To understand this interaction, separate ANOVAs were computed for each group. For bilinguals, the results showed no main effect of condition ($p > .8$), but for monolinguals, condition was significant, $F(1,13) = 25.53$, $p < .001$, indicating larger positive mean amplitudes for semantically anomalous (1.5μV) than for correct (0.14μV) sentences.

In the 250–350 ms latency window (LAN), there was no main effect of group or condition (*p*s>.9) but a significant effect of hemisphere, $F(1,26) = 5$, $p <.05$, indicating larger negative mean amplitudes over the left (−.81μV) than the right (−.17μV) hemispheres. This effect interacted with condition, $F(1,26) = 6.6$, $p <.05$, revealing negative mean amplitudes over the left (−1.03μV) and positive mean amplitudes over the right (0.05μV) hemispheres for syntactically incorrect sentences; and similar negative mean amplitudes in both hemispheres (right: −0.39μV; left: −0.59μV) for correct sentences. The interaction between group, condition, and hemisphere was not significant ($p>.9$).

Comparing the N400 (350–480 ms) for the correct and semantically anomalous sentences revealed an interaction between group and condition, $F(1,26) = 5.14$, $p < .05$ (see Figure 2b an 3b). Both groups showed comparable mean amplitude in correct sentences (bilinguals: −1.4μV; monolinguals: −1.4μV) but bilinguals showed larger negative amplitudes for semantic anomalous sentences (−2.2μV) versus correct sentences (−1.4μV), whereas this N400-effect was not present for monolinguals (i.e., −1.2μV and −1.4μV).

Comparing the correct and syntactically incorrect sentences, the P600 difference waves[3] indicated a main effect of group, $F(1,26) = 4.41$, $p < .05$, indicating smaller amplitude in bilinguals (−1.92μV) than in monolinguals (−3.33μV) (Figure 3b). For lateral electrodes[4] (P3/P4: 500–650ms), there was a significant interaction between group and hemisphere, $F(1,26) = 7.00$, $p < .05$. Separate ANOVAs for each group showed that there was no effect of hemisphere and no interaction between condition and hemisphere for bilinguals (all $p > .23$) but there was a main effect of hemisphere for monolinguals, $F(1,13) = 5.44$, $p < .05$, indicating smaller P600 over the right (0.28μV) than over the left (0.90μV) hemispheres (Figure 4b).

Discussion

The involvement of executive control in syntactic and semantic processing in monolinguals and bilinguals was investigated using scalp recording ERPs during word-by-word sentence reading and sentence judgments. It was hypothesized that ERPs would reveal the typical waves for semantic (N400) and syntactic (P600) violations for all participants, and this was clearly in line with the results of the present study. However, only the grammaticality task evoked an ELAN.

More importantly, our results showed that bilingualism modulated the N400 and P600 as a function of the executive function demands of the task. With the standard instructions for this type of research that we used in the acceptability task, bilinguals had lower accuracy levels than monolinguals, as in the research by Weber-Fox & Neville (1996). In contrast, the grammaticality task required executive control to confine the decision to the value for

[3]We examined difference wave on the late positive component (P600) to avoid sensory effects elicited by the following word.
[4]An analysis including only right-handed participants was conducted. Results showed significant interaction between group and hemisphere, $F(1,24) = 5.4$, $p < .05$.

grammaticality and ignore the meaning, and in this case, the bilingual group achieved the same level of accuracy as the monolingual group. Thus, in this more difficult task, bilinguals compensated for the deficit they showed in the simpler task. More importantly, bilingualism influenced the N400 and P600 time course and the P600 amplitude distribution.

Behavioral performance

Monolinguals and bilinguals were equivalent in all background measures except for English PPVT in which the monolinguals obtained higher scores, a finding consistent with previous literature (e.g., Portocarrero et al., 2007). Nonetheless, monolinguals were more accurate in the acceptability task. Thus, even at the behavioral level, the type of instruction produced different performance in the two groups. Our results are consistent with a compensatory mechanism available to bilinguals because of enhanced executive control through greater selective attention to conflicting values.

This pattern is comparable but not identical to the results reported for children in a similar task (Bialystok, 1986, 1988). In those studies, monolingual and bilingual children performed equivalently on the condition in which the meaning was intact and only linguistic knowledge was required to detect a grammatical error. However, bilingual children outperformed the monolinguals in the conflict condition in which attending to the meaning led to an incorrect response. Two reasons might explain why our results are not identical. First, the materials used in the children's study could not be used with ERPs methodology because of signal processing constraints (signal/noise ratio). Second, involving the same difficulty for adult and children is challenging in developmental language research; adults are language experts whereas children are just beginners.

Another comparison can be made with the performance of monolingual and bilingual adults on a verbal fluency task (Luo, Luk, & Bialystok, 2010). Bilingual participants whose English vocabulary scores were lower than those of the monolinguals, as in the participants in the present study, produced fewer words than monolinguals on the semantic fluency test based primarily on vocabulary knowledge. However, in the letter fluency task that requires both vocabulary knowledge and executive control, the bilinguals overcame this deficit and produced the same number of words as monolinguals. Similarly, the acceptability task is largely a measure of language proficiency, and the bilinguals with lower vocabulary levels performed more poorly on this task. However, the grammaticality task also incorporates the requirement for executive control to monitor and resolve the conflict, and as in the letter fluency, bilinguals performed as well as monolinguals.

Early components

It was hypothesized that the ELAN would be observed for monolinguals but not for bilinguals (Hahne & Friederici, 2001; Weber-Fox & Neville, 1996), but this was not found in the present study. The ELAN was comparable between groups but different between tasks. An early negativity wave was present in the acceptability task although it was not left-lateralized whereas in the grammaticality task both groups showed an ELAN wave. These results are consistent with several findings in the literature showing an early negative component over the left hemisphere (for an overview see Friederici, 2002). Similarly to the ELAN, the LAN was only lateralized in the grammaticality task. This finding is consistent with the results reported by Weber-Fox & Neville (1996). The LAN was also equivalent in amplitude for monolinguals and bilinguals. Our results suggest that the variable results in ELAN and LAN for syntactic processing in bilinguals may not only depend on factors such as age of acquisition (Weber-Fox & Neville, 1996) or L2 proficiency (Rossi et al., 2006) as previously suggested but also on the involvement of executive processing.

The groups also differed on a positive modulation between 160 and 200 ms related to the syntactic violation. For these sentences, monolinguals showed larger mean amplitudes than bilinguals. This effect was unexpected but is consistent with results reported by Moreno and Kutas (2005), although they did not report the statistical analysis on this time window.

N400 and P600 components

Our hypotheses were based on previous ERP studies examining N400 and P600 waves. As in that research, participants read sentences word by word and responded with a larger N400 to semantic anomalies than to semantically congruent words. Consistent with the results reported by Moreno and Kutas (2005) and Hahne and Friederici (2001), the N400 was equivalent in amplitude for monolinguals and bilinguals in the acceptability task. Nevertheless, our results showed a larger N400 in bilinguals than in monolinguals in the grammaticality task. Even when the task required focusing on grammaticality, bilinguals were able to process the semantic information. Consistent with the results reported by Rodriguez-Fornells et al. (2005), our data showed larger fronto-central negativity in bilinguals than in monolinguals. Those authors interpreted this result as evidence for the involvement of cognitive control. In the grammaticality task, this larger negativity could be interpreted in terms of bilinguals dealing with conflict in which they were judging the syntax and answering '*correct*' to a semantically anomalous sentence.

Some researchers have reported a longer latency for the brain response to semantic anomalies (N400 effects) in bilinguals than in monolinguals (Weber-Fox & Neville, 1996; Ardal et al., 1990), but our results did not show this difference. Weber-Fox and Neville (1996) explained their results in terms of late exposure to L2, but our bilingual population was composed primarily of early language learners, most of whom were exposed to English before 12 years old. In the grammaticality task, the results suggest that monolinguals did not process the semantic anomaly (no differences between correct and semantic anomalous mean amplitudes) but bilinguals were able to process it and achieve the same level of accuracy as monolinguals. These results are consistent with the behavioral literature with children (Bialystok 1986, 1988; Bialystok & Majumder, 1998; Ricciardelli, 1992; Cromdal, 1999).

As in the study by Weber-Fox and Neville (1996), greater differences were found in the syntactic than the semantic processes. All our participants responded to syntactic anomalies with a larger P600 than that for syntactically correct sentences. However, it was hypothesized that the processing demands of the task should be handled more efficiently by the bilinguals and this effect would be demonstrated by reduced amplitude for the P600 wave in the grammaticality task; this is exactly the pattern found in our results. Bilinguals demonstrated smaller P600 mean amplitudes than monolinguals but only in the more difficult grammaticality task. These results replicate the findings of Hahne and Friederici (2001) for linguistic judgments. Friederici (2002) interpreted the P600 as reflecting processes of reanalysis and syntactic repair. This definition suggests a link between control processing and P600. Several findings show that control mechanisms influence late positivity components (Mueller et al., 2009; Swainson et al., 2006). For example, Slagter et al. (2005), using a task in which participants were cued to direct attention to color and/or location, showed that control mechanisms such as attention imply modulation of late positivity components. The decrease in amplitude observed in our data can be related to these findings. One possible explanation for this decrease is the involvement of a smaller number of neurons to process the syntactic judgment in the context of competing values for grammar and meaning because of greater proficiency in executive control. Put another way, the greater efficiency of bilinguals to manage conflict between competing options is reflected in less effortful processing for conflict resolution.

As we hypothesized, processing syntactic anomalies also produced hemispheric differences between groups. In both tasks, bilinguals showed a more bilateral distribution of this effect than monolinguals who showed a left-lateralized network. Moreover, the instructions did not influence the network topographic organization of the syntactic processing. It could be argued that the required processing resources (i.e., the network topography) are the same in both tasks but the neuronal firing pattern is different in bilingual participants (P600 effect). Dehaene et al. (1997) demonstrated that L1 processing was more left-lateralized and L2 processing more bilateral. Similarly, Wartenburger et al. (2003) showed that the cortical representation for syntactic judgment was largely dependent on L2 age of acquisition. Our findings confirm these results showing that bilingualism influences the neuronal network involved in language processing.

Conclusion

These findings show that bilingual experience influences brain processing of sentence-level linguistic stimuli. Evidence from ERP in a linguistic judgment task that required selective attention revealed a bilingual advantage that was parallel to earlier behavioral evidence from bilingual children. As found for nonverbal tasks, selective attention and conflict resolution is less effortful for bilinguals than monolinguals, even in linguistic tasks for which their overall processing ability is less proficient or less automatic. The early acquisition of L2 syntactic knowledge and good language proficiency led to comparable brain processing between groups in a task based primarily on linguistic knowledge (acceptability task) but the time course of semantic and syntactic processing was modified for bilinguals when task demands also required greater executive control (grammaticality task). These results contribute to the larger enterprise of establishing more precisely how specific protracted experience modifies cognitive processes and networks.

Several future directions are opened by this study. One of them will be to extend this study to younger population such as children and to investigate the effect of development on these mechanisms. Another one will be to test bilinguals with English as L1 versus English monolinguals, and see if the benefit in the grammaticality task is still present. Finally, extending this paradigm to other kind of life experience such as music which involves high levels of control, attention, and memorization; and comparing it with bilingualism will help to qualify these life experiences influences.

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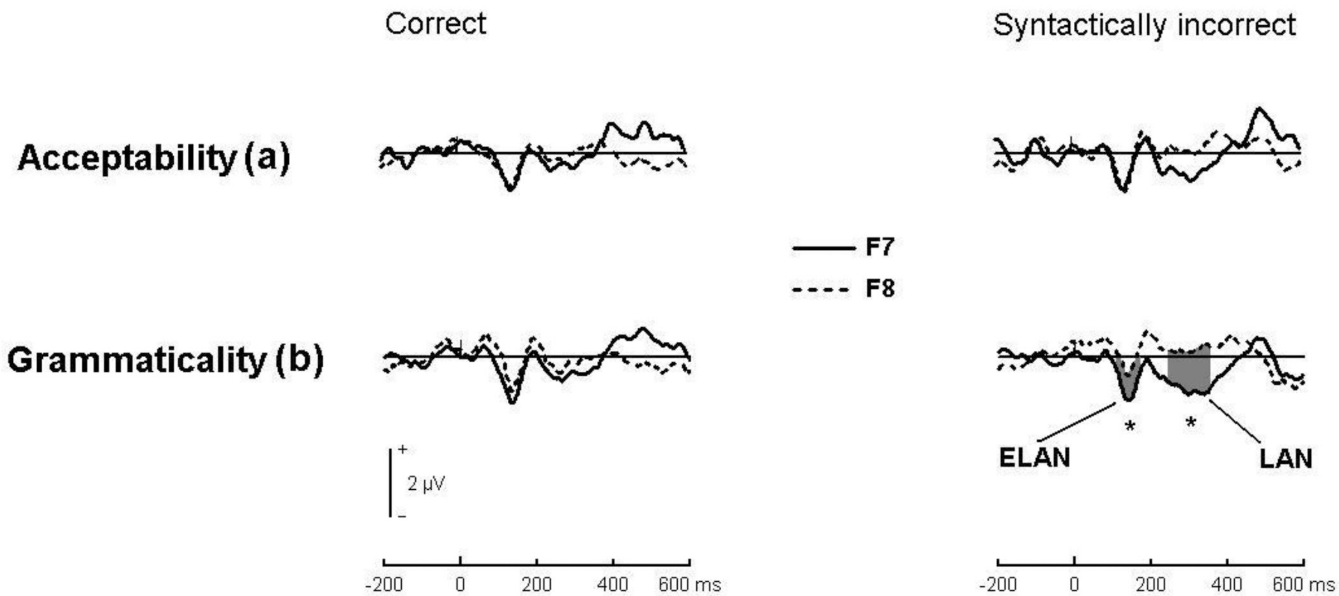

Figure 1. Early Left Anterior Negativity

Early Left Anterior Negativity and Left Anterior Negativity waves. Groups mean ERPs elicited by correct and syntactically incorrect sentences in (a) acceptability task and (b) grammaticality task at two frontal scalp sites: F7 (left hemisphere) and F8 (right hemisphere).

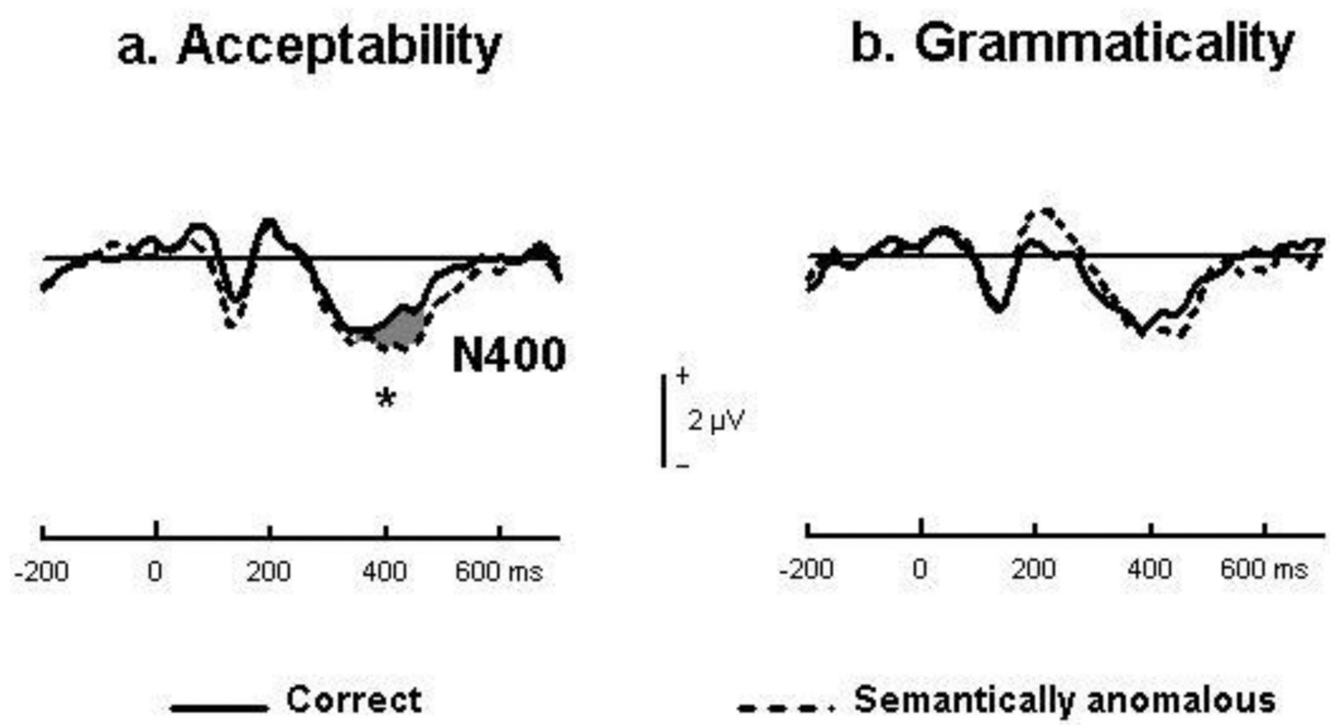

Figure 2. N400 All subjects

N400. Means ERPs elicited by semantically anomalous sentences in (a) acceptability task and (b) grammaticality task for all participants at the midline central scalp site (Cz).

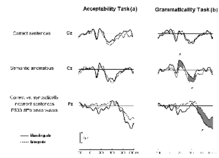

Figure 3. Monolinguals vs. Bilinguals 3 conditions in Acceptability and Grammaticality tasks
N400 and P600 difference wave effects. Group means ERPs elicited by correct, semantically anomalous and syntactically incorrect sentences in (a) acceptability task and (b) grammaticality task at the midline central (Cz) and parietal (Pz) sites.

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Fig 4a

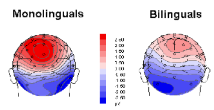

Fig 4b

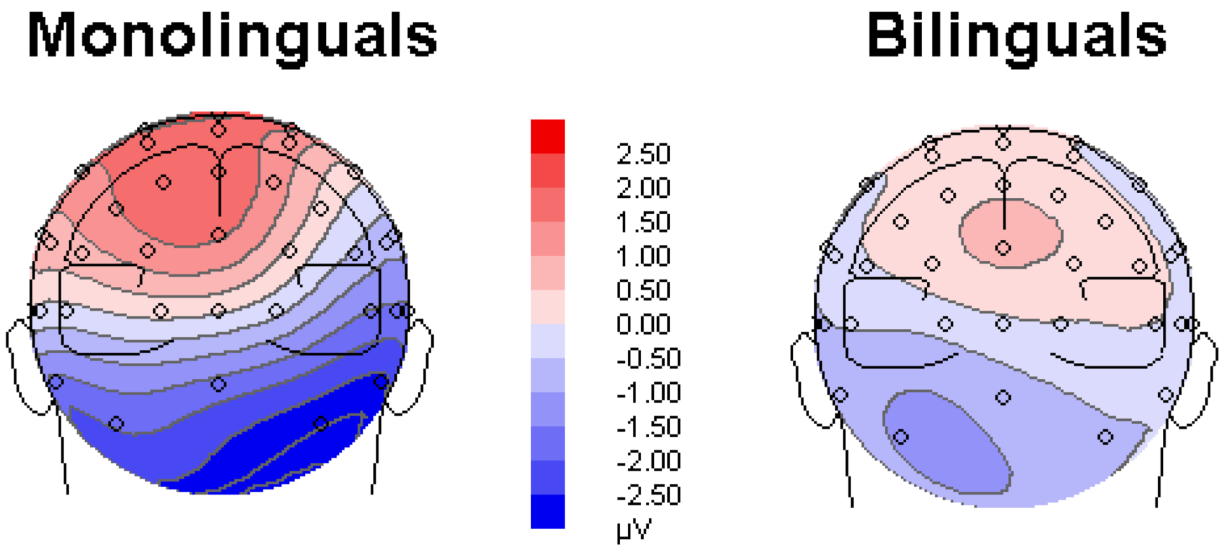

Figure 4.

a: Comparison of the brain map amplitude between monolingual and bilingual groups in the acceptability task. – do you plan for color or gray scale?

b: Comparison of the brain map amplitude between monolingual and bilingual groups in the grammaticality task. Same as above

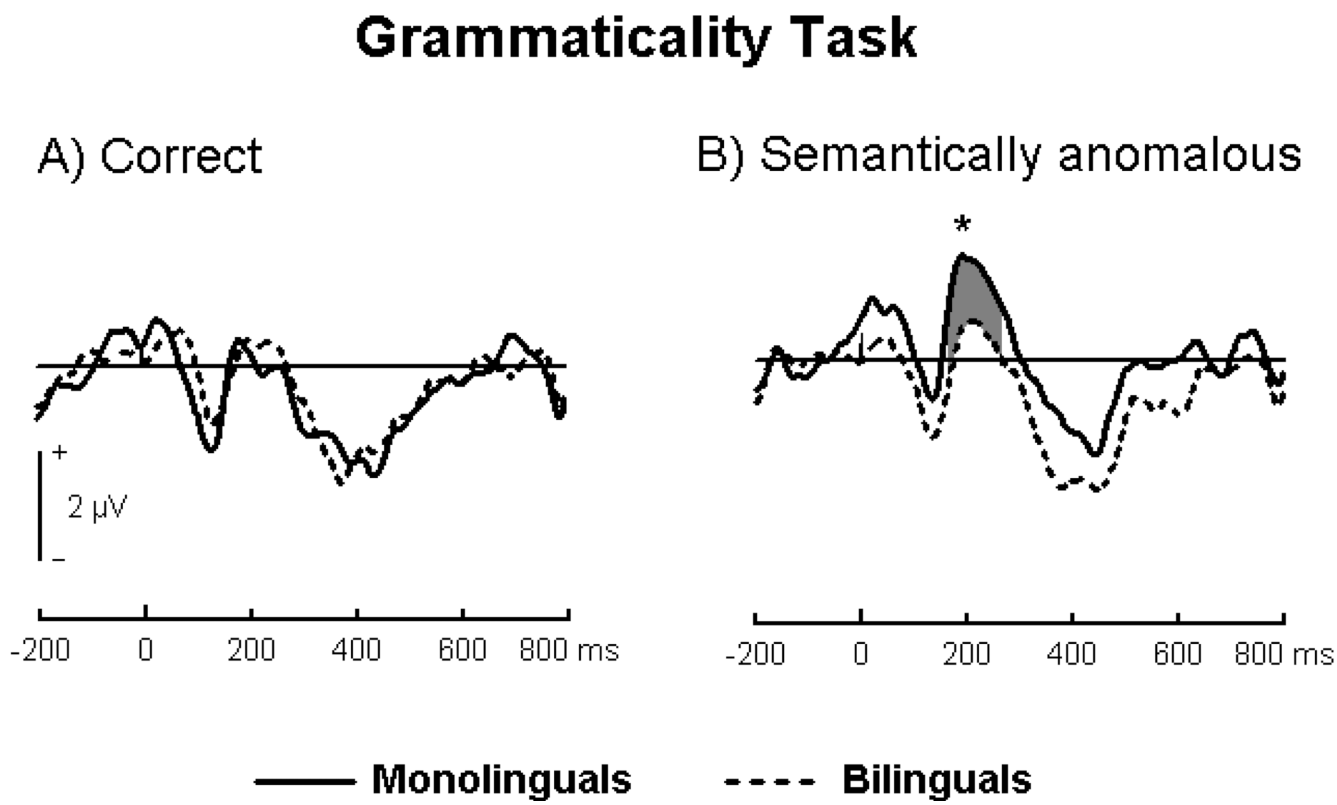

Figure 5. 160–260
Group means ERPs elicited by correct, semantically anomalous sentences in (a) acceptability task and (b) grammaticality task at the midline central scalp site (Cz).

Table 1

Stimulus sentences in the acceptability task and grammaticality task

	Semantically correct	**Semantically anomalous**
Syntax correct	A new computer will *last* for many years	A new computer will *paint* for many years
Syntax incorrect	A new computer will *lasting* for many years	A new computer will *painting* for many years

Table 2

Group means (and standard deviations) for background measures by language group.

	Age (in years)	Education (in years)	PPVT Std. English*	Corsi Score	Cattell Std.
Monolingual	23.6 (3.1)	17.3 (1.8)	109.2 (5.7)	17.4 (2.4)	117.1 (9.8)
Bilingual	23.5 (4.5)	16.8 (3.4)	103 (8.8)	16.6 (2.4)	115.6 (12.4)

* $p < .05$

Table 3

Group means (and standard error) for accuracy of judgments in acceptability task and grammaticality task for both groups in all conditions

		Acceptability task		Grammaticality task	
Group	**Condition**	**Mean**	**Std. Error**	**Mean**	**Std. Error**
Bilingual	Correct	0.90	0.02	0.95	0.01
	Semantically anomalous	0.81	0.03	0.93	0.02
	Syntactically incorrect	0.93	0.02	0.93	0.02
Monolingual	Correct	0.95	0.02	0.96	0.01
	Semantically anomalous	0.87	0.03	0.95	0.02
	Syntactically incorrect	0.95	0.02	0.96	0.02