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When bilinguals choose a single word to speak: Electrophysiological evidence for inhibition of the native language

Maya Misra,

Department of Communication Sciences and Disorders, The Pennsylvania State University,
University Park, USA

Taomei Guo,

State Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University, Beijing,
China

Susan C. Bobb, and

Department of Psychology, The Pennsylvania State University, University Park, USA

Judith F. Kroll

Department of Psychology, The Pennsylvania State University, University Park, USA

Abstract

Behavioral and event-related potential (ERP) measures are reported for a study in which relatively proficient Chinese-English bilinguals named identical pictures in each of their two languages. Production occurred only in Chinese (the first language, L1) or only in English (the second language, L2) in a given block with the order counterbalanced across participants. The repetition of pictures across blocks was expected to produce facilitation in the form of faster responses and more positive ERPs. However, we hypothesized that if both languages are activated when naming one language alone, there might be evidence of inhibition of the stronger L1 to enable naming in the weaker L2. Behavioral data revealed the dominance of Chinese relative to English, with overall faster and more accurate naming performance in L1 than L2. However, reaction times for naming in L1 after naming in L2 showed no repetition advantage and the ERP data showed greater negativity when pictures were named in L1 following L2. This greater negativity for repeated items suggests the presence of inhibition rather than facilitation alone. Critically, the asymmetric negativity associated with the L1 when it followed the L2 endured beyond the immediate switch of language, implying long-lasting inhibition of the L1. In contrast, when L2 naming followed L1, both behavioral and ERP evidence produced a facilitatory pattern, consistent with repetition priming. Taken together, the results support a model of bilingual lexical production in which candidates in both languages compete for selection, with inhibition of the more dominant L1 when planning speech in the less dominant L2. We discuss the implications for modeling the scope and time course of inhibitory processes.

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Direct Correspondence to: Taomei Guo, State Key Laboratory of Cognitive Neuroscience and Learning, Beijing Normal University, Beijing, 100875, P.R. China, Telephone: 86-10-58802005, Fax: 86-10-58806154, guotm@bnu.edu.cn.

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Keywords

lexical selection; language production; inhibition; bilingualism

When a bilingual plans to speak even a single word, alternatives in both languages appear to be activated in parallel (e.g., Colomé, 2001; Costa, Miozzo, & Caramazza, 1999; Hermans, Bongaerts, De Bot, & Schreuder, 1998; Kroll, Bobb, & Wodniecka, 2006). This process might be expected to produce a high rate of errors in bilingual speech, but errors in which the incorrect language is spoken are rare (e.g., Gollan, Sandoval, & Salmon, 2011). Bilinguals must, therefore, develop a control mechanism that allows them to function in one language at a time, while still maintaining the ability to switch languages (e.g., Green, 1998; Muysken, 2000; Myers-Scotton, 2002).

Two alternatives have been suggested to solve the bilingual control problem. One assumes that bilinguals are able to consider only lexical candidates in the intended language, effectively ignoring the parallel activation of the other language (e.g., Costa et al., 1999; Finkbeiner, Gollan, & Caramazza, 2006). The other solution assumes that all activated candidates compete for selection, but that a relatively late-acting process reduces the activation of competitors in the non-target language to enable selection within the language in use (e.g., Green, 1998; Hermans et al., 1998). In theory, a number of different mechanisms might accomplish late language selection, but recent studies suggest that there may be inhibition of the stronger L1 to enable production of the weaker L2 (e.g., Levy, McVeigh, Marful, & Anderson, 2007; Linck, Kroll, & Sunderman, 2009; Philipp, Gade, & Koch, 2007; Philipp & Koch, 2009). Because few bilinguals are truly balanced, the asymmetry observed in these past studies (i.e., where L1 may be inhibited more than L2) is likely to characterize the situation for even highly proficient late bilinguals who are more dominant in one of the two languages, typically the native language.

Although there has been extensive discussion about how different components of cognitive control might be affected by bilingualism (e.g., Abutalebi & Green, 2007; Colzato et al., 2008; Festman, 2011; Garbin et al., 2010; Luo, Luk, & Bialystok, 2010), there has been less attention to the issue of the scope and time course of inhibition. With respect to scope, an inhibitory mechanism could potentially operate at a local level, inhibiting specific lexical candidates, or at a global level, inhibiting one of the bilingual's languages entirely (e.g., De Groot & Christoffels, 2006; De Groot, 2011; Neumann, McCloskey, & Felio, 1999). In theory, the scope of inhibition may be continuous, with intermediate alternatives possible as well that are defined by semantic or contextual properties (e.g., a given semantic category might be suppressed). With respect to time course, inhibitory mechanisms may be relatively short-lived or may show more sustained effects. Studies of bilingual word recognition that have examined the consequences of resolving cross-language competition for language ambiguous words suggest that there is a relatively short time course of inhibition, presumably because the inhibitory mechanism is operating locally (e.g., Blumenfeld & Marian, 2011; Ibáñez, Macizo, & Bajo, 2010; Macizo, Bajo, & Martín, 2010). In the domain of production, the contrast between local and global inhibition has focused primarily on the issue of scope with respect to what is inhibited (e.g., De Groot & Christoffels, 2006), not particularly on the question of how long that inhibition lasts. In the present study, we begin to address the issue of time course using an ERP paradigm that may provide a sensitive index of the earliest stages of speech planning and a blocking design that allows an assessment of the longer time frame over which inhibitory processes may operate.

Past studies have investigated the mechanisms underlying lexical selection during bilingual speech by examining the consequences of required switches from one language to the other.

The logic of this approach, based on the task switching paradigm (e.g., Allport, Styles, & Hsieh, 1994), is to present language ambiguous information (e.g., pictures or numbers) and to then cue the required language of naming. Initial studies on language switching reported asymmetric switch costs, with longer response times when bilinguals switch from the L2 into the L1 than the reverse (Meuter & Allport, 1999). This result has been interpreted to mean that naming in L2 requires that the dominant L1 be inhibited; returning to naming in L1 following naming in L2 then involves overcoming that inhibition. In contrast, when naming in L1, the weaker L2 is assumed not to require inhibition to the same degree. The observed asymmetric switch costs are thought to reflect the subsequent processing consequences of the hypothesized L1 inhibition.

This account of language switching has been challenged by other studies that have failed to obtain asymmetric language switch costs and have taken that failure as evidence against the idea that inhibition is required to control bilingual speech. Symmetric switch costs have been observed when bilingual speakers are highly proficient and relatively balanced in the dominance of the two languages (e.g., Costa & Santesteban, 2004), when the decision about which language to select is left to the speaker (e.g., Gollan & Ferreira, 2009), and when there is an extended interval in which to prepare for the switch (e.g., Verhoef, Roelofs, & Chwilla, 2009). Costa and Santesteban (2004) proposed that inhibition, and the corresponding asymmetric switch costs, might be needed when individuals are not fully proficient in the L2, but that once a high level of L2 skill is achieved, the intended language can be selected without inhibition. However, what is striking in the results of many language switching studies is that even when there is no switch cost asymmetry, naming in L1 is often slower than in L2, suggesting that the L1 is indeed inhibited under mixed language naming conditions (Kroll, Bobb, Misra, & Guo, 2008) even when the bilingual speakers are highly proficient in both languages.

A set of recent behavioral experiments using the n-2 repetition paradigm (Mayr & Keele, 2000) also suggests that the symmetry or asymmetry of immediate costs in language switching may not be the most reliable indicator of the presence of inhibitory processes. In this paradigm, participants switch among three tasks (e.g., A, B, C) and each task has two task sequences. For example, task A may include the n-2 repetition condition (e.g., ABA) and the n-2 non-repetition condition (e.g., CBA). In each case, the immediately preceding trial is the same but the n-2 trial is different. Participants are slower in the n-2 repetition condition than in the n-2 non-repetition condition, which has been termed the n-2 repetition cost (Mayr & Keele, 2000). Philipp et al. (2007) and Philipp and Koch (2009) adapted this paradigm to examine the naming performance of trilinguals when they switched between three rather than two languages. Under conditions of an n-2 language repetition (e.g., German-English-German), they found that relative to no repetition (e.g., French-English-German), there was a cost to processing speed. Philipp et al. interpreted the n-2 repetition cost as inhibition of the previously active language. Critically, the n-2 repetition cost was observed even when the immediate switching conditions from trial to trial were identical, suggesting that the presence of inhibition is not controlled by local processes alone.

Several recent studies have also used event-related potentials (ERPs) to evaluate the time course of language switching, with much of the research focusing on the N2 component. This negative-going deflection in the ERP waveform peaks at about 250-350 ms post stimulus onset and is typically maximal at centrofrontal sites. The N2 is typically generated when a response must be suppressed such as in the no-go trials of a go/no-go task (e.g., Van Boxtel, Van der Molen, Jennings, & Brunia, 2001). It is often described as an index of general control process (Nieuwenhuis, Yeung, & Cohen, 2004) although there is controversy as to whether it reflects inhibitory processes (e.g., Falkenstein, Hoormann, & Hohnsbein,

1999) or response conflict (e.g., Nieuwenhuis, Yeung, Van den Wildenberg, & Ridderinkhof, 2003).

In order to avoid movement artifacts induced by overt naming, some ERP studies on language production have adopted an adaptation of the go/no-go task with a tacit picture naming task and used the N2 as an index to examine the temporal course of information retrieval (Guo & Peng, 2007; Rahman & Sommer, 2003; Rodriguez-Fornells, Schmitt, Kutas, & Münte, 2002; Schmitt, Münte, & Kutas, 2000; Schmitt, Rodriguez-Fornells, Kutas, & Münte, 2001; Schmitt, Schiltz, Zaake, Kutas, & Münte, 2001). Evidence for inhibition of the non-target language in bilingual language production has been reported in these ERP studies. For example, in the study by Rodriguez-Fornells, Van der Lugt, Rotte, et al. (2005), German-Spanish bilinguals were required to respond when the name of a picture had a consonant initial phoneme and to withhold a response for names with a vowel initial phoneme. The pictures were selected such that on half of the trials, the names in both languages (Spanish and German) would lead to the same response, whereas on the remaining trials, responses were different for the two languages. An enhanced N2 was found between 300 to 600 ms for incongruent as compared to congruent trials. These results were taken as evidence for a general cognitive control mechanism that was hypothesized to be recruited to suppress cross-language interference in bilingual word production (for reviews, see Moreno, Rodriguez-Fornells, & Laine, 2008; Rodriguez-Fornells, De Diego Balaguer, & Münte, 2006; Ye & Zhou, 2009).

Recent ERP studies have used the language switching task to test the hypothesis that bilinguals select words in the intended language by inhibiting the unintended language (Green, 1998), with care to avoid contamination from movement artifact. These studies have predicted that language switching should also lead to a more negative N2 component, and language switching effects have indeed been observed on the N2 (e.g., Christoffels, Firk, & Schiller, 2007; Jackson, Swainson, Cunnington, & Jackson, 2001; Verhoef et al., 2009). However, unlike the behavioral evidence, the ERP studies have failed to report a consistent pattern. Jackson et al. reported a larger N2 for switch than no-switch conditions in a digit naming task, but only when bilinguals named digits in their L2. No effect was observed in L1. In the behavioral data for the same experiment, they found the standard switch-cost asymmetry reported by Meuter and Allport (1999), with larger switch costs in naming the L1 following the L2. Subsequent ERP studies of language switching have not fully replicated the pattern reported by Jackson et al. (2001). Christoffels et al. (2007) examined language switching in a picture naming task with German-Dutch bilinguals. Unlike the Jackson et al. results, Christoffels et al. found a significant effect on the N2 for naming in L1 but not for naming in L2. Moreover, the direction of the N2 effect in the Christoffels et al. study was the opposite of what had been observed by Jackson et al.; they found a larger N2 for L1 in the no-switch conditions than in the switch conditions. Unlike either of the other two ERP switching experiments, Verhoef et al., testing Dutch-English bilinguals, found no differential N2 effect for switch versus no-switch conditions. However, they did find that preparation time affected the N2, with a more negative N2 when the cue to select the response language was delayed relative to the presentation of the picture. At best, the overall pattern in these ERP studies of language switching is mixed, with some evidence for inhibitory processing but little evidence that allows a firm commitment to the locus of an inhibitory mechanism (and see Kroll et al., 2006, for an analysis of why there may be alternative loci for language selection in the process of speech planning).

A finding in the Christoffels et al. (2007) ERP study provides a further suggestion that there may be more than a single locus of inhibitory control. Christoffels et al. examined picture naming under mixed and blocked language conditions. In typical language switching experiments, all performance is assessed in the context of mixed language naming, so that

both switch and no-switch trials occur in a larger context in which both languages are named. However, while switch trials can only be examined in the mixed language context, no-switch trials can be compared in both mixed and blocked language conditions to assess the consequences of knowing or not knowing the language of naming in advance. Christoffels et al. found that there was greater negativity in mixed no-switch trials than in blocked conditions, consistent with the behavioral results on the n-2 repetition paradigm (Philipp & Koch, 2009), suggesting that there may be multiple components of inhibition. Christoffels et al. also reported larger effects of language mixing for L1 relative to L2 (see Kroll, Dijkstra, Janssen, & Schriefers, 2000, and Sunderman, 2002, for similar behavioral evidence of differential costs of language mixing).

More recently, Guo, Liu, Misra, and Kroll (2011) used functional magnetic resonance imaging (fMRI) to examine the neural consequences of language mixing and language blocking. Chinese-English bilinguals named pictures in three blocks. In the first two blocks, the language of naming was blocked so that pictures were named in English or in Chinese, with the order of language counterbalanced across participants. In the final block, all participants named pictures in a mixed language list. The effect of language[^] mixing, in which the language of production switched within a list, was compared with the effect of language blocking, in which the language of production switched across lists. Critically, each of these conditions produced evidence for activation of neural areas associated with cognitive control and inhibitory processes, but different patterns were associated with each comparison. The dorsal anterior cingulate cortex (ACC) and the supplementary motor area (SMA) appeared to play an important role during language switching, whereas the dorsal left frontal gyrus and parietal cortex appeared to be more important during language blocking. Guo et al. hypothesized that differential activation observed in each of these conditions reflected the contribution of local vs. global inhibitory mechanisms, with switching reflecting local inhibition and blocking reflecting global inhibition. Other fMRI studies of bilingual speech planning have shown that the neural mechanisms associated with cognitive control are differentially active when bilinguals select between their two languages relative to when they make a lexical selection in a within-language task (e.g., Abutalebi et al., 2008). These studies show that language switching and language selection activate a network of areas associated with cognitive control including prefrontal cortex, ACC, posterior parietal cortex, and basal ganglia (e.g., Hernandez, Martinez, & Kohnert, 2000; Hernandez, Dapretto, Mazziotta, & Bookheimer, 2001; Wang et al., 2007; Rodriguez-Fornells et al., 2005; see Abutalebi & Green, 2007; Rodriguez-Fornells, Balaguer, & Münte, 2006; for reviews).

In the current experiment, we followed the logic of the Guo et al. (2011) study but used both ERPs and behavioral measures to investigate the effects of blocked language switching on picture naming in Chinese-English bilinguals. Unlike previous studies comparing switch versus no-switch trials during a mixed language naming task, we sought to evaluate the immediate and potentially longer lasting inhibitory components that have been implicated in the studies reviewed above. Participants completed an entire block of naming within one language and were then asked to name the same pictures in the other language. In this way the picture would have been identified and the name for the object would have already been retrieved in one language, and the later block would only require retrieval of the alternate name of the object in the other language. Under these conditions, we would typically expect to see facilitation in the form of repetition priming. However, if naming in a given language produces inhibition of the other language, then priming should be reduced or eliminated. In addition, by maintaining the same language over a block of trials, the type of cognitive control required should differ from that required in the mixed language naming context that has been typically used to examine language switching. Alternations of language within a block of trials in the standard language switching paradigm may require the allocation of

additional cognitive resources to keep track of which language must be named. The blocked switching paradigm provides a new approach to examining inhibitory control that does not require attention to the decision of which language is to be used and that also addresses a concern raised by Costa, La Heij, and Navarrete (2006) about the use of switching tasks to evaluate evidence for parallel activation of a bilingual's two languages during production (see also Grosjean, 2001, and Wu & Thierry, 2010). Bilinguals are rarely asked to switch back and forth between their two languages while naming pictures presented in series, so these authors argue that experiments must be restricted to a single language to evaluate evidence for parallel activation in common settings. While both languages are invoked across blocks in the current study, the blocked switching eliminates the need to frequently alternate between languages. A bilingual, by definition, may be placed into situations during the course of a day when a switch may be required from one language to another. Even bilinguals who do not ordinarily engage in code switching in the sense of switching frequently within a sentence or local discourse (e.g., Dutch-English bilinguals or the Chinese-English bilinguals tested in the present study) will switch languages over a more extended period of time.

As noted above, the conditions that we report might be predicted to generate repetition priming for identification of a picture, facilitating the speed of naming for repeated items relative to those named first. In ERP studies, repetitions of pictures or words, even over a delay, typically produce more positive waveforms than first presentations (e.g., Guillaume et al., 2009; Rugg & Nagy, 1989). Previous studies evaluating immediate cross-language priming effects during silent word reading have also found positive ERP shifts with both repetition and translation priming (e.g., Alvarez, Holcomb, & Grainger, 2003). However, if naming a picture in one language requires inhibition of the name in the language not in use, then the observed facilitation may be reduced or eliminated. The magnitude of these effects might also be expected to depend on language dominance, with greater predicted inhibition for the more dominant language when the weaker of the two languages is spoken. Note that the contribution of an inhibitory component does not eliminate priming, but, taken together with the priming expected from the repetition of the picture and concept, may sum to a net result that no longer reflects facilitation.

An unusual feature of the present experiment relative to other research on language production is that we did not pre-train participants on the desired picture names and we carefully controlled the number of repetitions of each picture. Eliminating pre-training increases the presence of missing cells but is necessary given the scientific goal of examining language selection in L2 production. Studies using the transfer appropriate processing paradigm have shown that pre-training during the study phase of an experiment induces robust repetition priming at test (e.g., Francis, Augustini, & Saenz, 2003; Hernandez & Reyes, 2002; Sholl, Sankaranarayanan, & Kroll, 1995). Furthermore, neuroimaging studies (e.g., Van Turennout, Biellamowicz, & Martin, 2003) have demonstrated long-lasting changes in brain activity following a single picture naming trial. Because pre-training is unlikely to have the same consequences for the L1 as the L2 (e.g., Francis & Sáenz, 2007), the cost of a somewhat higher error rate for L2 naming was judged to be more acceptable than an induced lexical bias in the current study. Furthermore, item repetitions were controlled to allow for evaluation of context effects. Each picture was named in both languages to evaluate whether previously naming a picture in one language impacts later processing of that same lexical item in another language when presented in a separate block. In addition, each picture was repeated once within each language, for a total of four presentations of each item. The repetition in the first naming language served to enhance any effects of language context based on retrieving the item's name in a given language, and comparisons were then made between the first naming trial in each language (i.e., the first and third time a picture was presented). Repetitions in the subsequent naming language were

used to evaluate whether effects observed in the “switch” block persisted after an initial naming trial in the new language. Thus, the first and fourth presentations of each picture were also compared¹.

If naming pictures in the L2 requires relatively proficient but L1 dominant bilinguals to inhibit the L1, then picture naming should reveal inhibitory processing when bilinguals switch from the L2 into the L1. Critically because switching follows a block of extended picture naming in one language only the predicted inhibitory effects in L1 should be short lived if only the switch from the most recent L2 trials to the first set of L1 trials are relevant. Bilinguals should be able to recover from momentary inhibition of the L1 once they repeatedly use the L1 again. In contrast to the prediction for switching blocks from L2 to L1, when the sequence of picture naming switches from L1 to L2, if there is no need to inhibit L2 during L1 naming, then we predicted repetition priming reflecting a benefit in processing at the second time of naming.

Method

Participants

Thirty-six Chinese-English bilinguals in Beijing, China, participated in this experiment. All participants had normal or corrected-to-normal vision and were free of neurological disorders. They were randomly divided into two groups of 18 individuals. Both groups completed a blocked naming task. Group A first named pictures in L1, and then named the same set of pictures in L2. Group B first named pictures in L2, and then named the pictures in L1. Two participants in Group B were excluded due to excess artifact, leading to final group sizes of 18 participants in Group A and 16 participants in Group B. Each participant received a small amount of money for his/her participation in the experiment.

Participants averaged 21.7 years of age, all late bilinguals who began to learn English at approximately age 12 and had no study abroad experience. They were dominant in their L1 (Chinese) in reading, writing, speaking, and listening skills, as self-reported on a language history questionnaire. Table 1 summarizes the profile of each group.² Since the current experiment required a comparison between groups, we performed several analyses to ensure that the two groups were closely matched on demographic variables and language proficiency. A series of independent samples *t* tests showed that the two groups were not significantly different in age or the number of years spent studying English, $t(32) < 1$. In addition, a two-way ANOVA on the language self-ratings confirmed that both groups were more proficient in their L1 than their L2, $F(1, 32) = 77.74$, $p < 0.001$; but there was no difference between the two groups, $F(1, 32) < 1$. Participants also did not differ significantly in attentional control, as measured by a Simon task, $t(32) < 1$, or in memory resources, as measured by a reading span task administered in English, $t(32) = 1.22$, $p > 0.2$. The reading

¹The design of the current experiment also allows for analysis of simple within-language repetition effects, particularly for Blocks 1 and 2, before potential effects of language switching might occur. For these comparisons, we did observe expected repetition effects (reduced RTs and less negative ERPs). However, these effects are not central to the core questions posed in the current paper and are therefore not discussed further here. In theory, the comparison of Blocks 2 and 3 could also be used to provide another way to examine the inhibition issue by comparing repetitions both within and between languages. However, we opted not to include this comparison, since Block 2 would be expected to have large within-language repetition effects at both semantic and lexical levels, while Block 3 may provide a better estimate of cross-language repetition at the semantic level alone. In addition, naming in L2 has been shown to benefit more from repetition than L1 (e.g., Hernandez & Reyes, 2002), which is likely to reduce the apparent differences between naming in L2 and in L1 in Block 2. Therefore, we focused on the comparisons between Blocks 1 and 3 and Blocks 1 and 4 in the current paper.

²The bilinguals who participated in this study were dominant in Chinese as the L1 but relatively proficient in English as the L2. They tended to rate their proficiency modestly in both Chinese and in English. Previous studies have reported similar differences in self-ratings across bilingual groups that appear to be the result of cultural differences but that do not affect on-line language processing performance (e.g., Hoshino & Kroll, 2008). Critically, the two groups that served as the between-group comparison in the present study were closely matched on demographic variables and language proficiency.

span task also served as an independent measure of language proficiency because participants were required to process and store sentences in their L2.

Materials

Line drawings sampled from a wide range of semantic categories were selected from the online database of the International Picture Naming Project (Szekely et al., 2004). A total of 72 pictures were used for the formal experiment, and 8 additional pictures were used for the practice trials. One third of the pictures in each block (24) were named at a short duration, such that a naming cue was presented 250 ms after onset of the picture. The remaining pictures (48) were named at a long duration (i.e., a naming cue was presented 1000 ms after onset of the picture). As explained below, short duration trials were used for behavioral data collection, and long duration trials were used for ERP data analysis.

Pictures were matched on visual complexity and frequency of the picture's most common name in English within each duration condition. Trial order was pseudorandomized and counterbalanced across participants. Each participant completed four naming blocks. The first and second blocks were in one language, and the third and fourth blocks were in the other language. The same pictures were used for each of the four blocks. Thus, pictures were repeated once per language, but repetitions appeared only after all items had been named once. When items were repeated within language, they appeared in the same duration condition as in the first presentation, but the order of item presentation differed. Items in the later language blocks were repeated in the same order and duration conditions as in the initial language blocks, with only the language of naming differing. The logic of keeping the item order the same for both language blocks was to maintain the distance between each language presentation. So for each item, the intervening number of trials from one presentation to the next should be the same, which is potentially important if we expect that there may be differential facilitation or inhibition depending on the order of the two languages.

Procedure

Each trial began with a fixation cross for 500 ms, and then a picture appeared after a blank screen of 300 ms. Pictures were presented on a white background which was centered on a colored frame. Pictures were to be named in L1 if the frame was red or in L2 if the frame was blue. However, since the language of naming varied by block and there are multiple cues to language membership in daily life as well, frame color acted as a redundant cue to which participants did not need to attend. Participants were instructed to name pictures as soon as possible after a border of asterisks (***) appeared around the image (inside the frame). Asterisks were presented at either 250 or 1000 ms following the onset of the picture, based on the paradigm used by Jackson et al. (2001). Delayed naming was used to enable artifact-free data collection in the ERP experiment, with only the 1000 ms trials being used for ERP data analyses³. The short duration trials were designed to encourage participants to be ready with a rapid response, minimizing strategic effects associated with delayed naming. These short duration trials were analyzed for behavioral measures of reaction time (RT) and accuracy. The task was self-paced such that participants pressed a button to initiate the next trial after naming a picture. The interval between two trials was 500 ms.

³Recent ERP studies that have examined production in both monolingual and bilingual naming contexts (e.g., Christoffels et al., 2007; Janssen et al., 2011; Verhoef et al., 2009) suggest that the delay manipulation used in the present experiment may not be necessary, since movements tend to be initiated after the early part of the recording epoch. At the time that the present experiment was designed, there were few published ERP studies using overt picture naming. The decision to use a design that included a delay was considered a conservative measure with respect to controlling for artifacts and also allowed us to examine the temporal course of inhibition by looking at ERP components occurring later than the N2 reported in previous studies. See Morell et al., 1971; Brooker & Donald, 1980; and Wohler, 1993, for further discussion on the effects of muscle artifacts in overt naming on EEG recordings.

The experiment was carried out in an isolated, quiet room. Participants were instructed to name pictures aloud once the asterisks appeared while moving as little as possible and refraining from blinking during the presentation of pictures. A break was provided between blocks. The entire session lasted approximately 1.5 hours, including electrode placement and removal.

Behavioral Data Analysis

Only trials at the short duration were included in the behavioral data analyses. RTs for correct naming trials below 300 ms and above 3000 ms were excluded as outliers, and a secondary trimming step was used to exclude naming latencies 2.5 standard deviations above or below each individual's mean value. This procedure identified 10.25% of correct naming trials as outliers across all behavioral conditions. Since the present study did not pre-train subjects on picture names, relatively liberal criteria were used to judge whether a picture was named correctly. Specifically, items named correctly, items for which the name was somewhat imprecise but correct (e.g., “clothes” for “blouse”), pronunciation errors in L2, and repetitions (which were correct) were identified as correct answers.

A series of 2 (language: L1/L2) * 2 (task order: first/second) ANOVAs evaluated how the order of the language of naming impacted performance in the blocked naming conditions for both RTs and error rates. For the first set of analyses, the differences between the initial language of naming and the subsequent language of naming were compared for the first and third presentation of each picture (i.e., the first time the picture was presented in each language). In the second set of analyses, the first and fourth presentations were compared to determine whether any effects observed in the first set of analyses persisted. Recall that pictures were presented for the first and second times in one language of naming, and pictures were then presented for the third and fourth times in the other language of naming. For these comparisons, language was a within-subject factor, while task order was a between-subject factor.

EEG data acquisition and analysis

The electroencephalogram (EEG) was recorded from a Quik cap (Neuroscan Inc.) including electrodes at the following International 10-20 locations: O1/OZ/O2, P3/PZ/P4, CP3/CPZ/CP4, TP7/TP8, C3/CZ/C4, T7/T8, FC3/FCZ/FC4, FT7/FT8, F3/FZ/F4, F7/F8, FP1/FP2. All electrodes were referenced to the left mastoid during recording and re-referenced offline to linked mastoids. Bipolar horizontal and vertical electro-oculographic (EOG) activity was recorded for artifact rejection purposes. Vertical EOG was recorded from two electrodes placed above and below the left eye. Horizontal EOG was measured by two electrodes placed at the outer canthus of each eye. Electrode impedances were kept below 5 kilo-Ohms (k Ω). The EEG signals were continuously recorded with a band-pass from 0.05 to 100 Hertz (Hz) with a sampling rate of 500 Hz. ERPs were digitally filtered at a low-pass of 30 Hz (24 dB setting).

Using the criteria described above, only correct, artifact-free trials in the long duration condition were included in the ERP analyses. To allow for adequate signal-to-noise ratio, the minimum number of trials for computing average ERPs for each condition in each participant was 30. As noted above, two participants from Group B were excluded due to excess artifact. For the participants included in the final sample, 8.3% of trials were rejected after excluding trials with errors and artifacts, with 7.6% rejected for Group A (3.5%, 3.7%, 12.5%, and 10.6% for Blocks 1, 2, 3, and 4, respectively), and 9.0% rejected for Group B (15.2%, 12.4%, 3.4%, and 4.9% for Blocks 1, 2, 3, and 4, respectively). Average ERPs were computed for each condition using a pre-stimulus baseline of 100 ms and an epoch duration of 1000 ms post stimulus onset (where the stimulus is the presentation of the picture, not the

asterisks). On the basis of visual inspection, components were selected for statistical analyses as described in the results section below. For each component, mean amplitudes over a set time window were computed as dependent variables. For each dependent variable, 2 (language: L1/L2) * 2 (task order: first/second) ANOVAs were computed comparing Blocks 1 and 3 and Blocks 1 and 4. Order of picture naming served as a between-subjects factor for these analyses. Based on the topographical distribution of the effects we were interested in, separate analyses were completed for the midline and lateral sites. For the midline sites, six levels of electrode site (Oz, Pz, CPz, Cz, FCz, Fz) were included as a third variable. For the lateral sites, variables of hemisphere (2: left/right) and electrode site (11 levels: O1/O2, P3/P4, CP3/CP4, C3/C4, TP7/TP8, T7/T8, FT7/FT8, FC3/FC4, F3/F4, F7/F8, FP1/FP2) were factored into the ANOVA. When appropriate, the Greenhouse-Geisser correction was applied to account for non-sphericity of the data (Greenhouse & Geisser, 1959); uncorrected degrees of freedom and corrected probabilities are reported. Only results including the factors of language of naming or task order as main effects or interactions between these factors and electrode site and/or hemisphere are reported, since general topographic differences in electrode site and/or hemisphere per se are to be expected and are not of primary interest in this study.

Results

Behavioral Data

Table 2 shows the average RTs and error rates for the groups in each condition. As discussed above, each picture was repeated once in each language, for a total of four presentations, once in each block. Data for the first two naming blocks in L1 and the last two blocks in L2 were contributed by participants in Group A; the remaining data were contributed by Group B. Because our interest was in cross-language effects on picture naming, initial analyses focused on the first naming trial in each language, which corresponded to the first and third time a picture was presented. The first and fourth presentations of each picture were also compared to evaluate whether any inhibitory effects observed in the initial comparisons persisted after a naming trial in the new language. Within-language repetition effects are not discussed, although they can be seen in the values presented in Table 2.

Comparison of Blocks 1 and 3—In the RT analyses, the main effect of language, $F(1, 32) = 34.79$, $p < 0.001$, and the interaction between language and task order, $F(1, 32) = 24.13$, $p < 0.001$, were significant. As might be expected, picture naming latencies were faster in the L1 than in the L2 (e.g., Christoffels et al., 2007; Potter, So, von Eckardt, & Feldman, 1984). Further independent samples t tests revealed that task order produced no significant effect in L1, but naming in L2 second (i.e., after naming in L1) was significantly faster than naming in L2 first, $t(32) = -3.06$, $p < 0.01$. Although the pictures named in each block were identical, L1 revealed no benefit when named following the blocks of naming in the L2.

In the analyses of error rates, the main effect of language was significant, $F(1, 32) = 62.62$, $p < 0.001$, indicating that more errors were made in L2 naming overall. However, the main effect of task order and the interaction between language and task order were not significant.

Comparison of Blocks 1 and 4—In the RT analyses, there were significant main effects of language, $F(1, 32) = 8.62$, $p < 0.01$, and task order, $F(1, 32) = 5.82$, $p < 0.05$. Furthermore, the interaction between language and task order was significant, $F(1, 32) = 84.35$, $p < 0.001$. Post-hoc independent samples t tests revealed that, although the difference was larger for L2, task order caused a significant effect on naming in both L1, $t(32) = 2.14$,

$p < 0.05$, and L2, $t(32) = 5.69$, $p < 0.001$, such that naming in the fourth block was faster than the first block for each language. The smaller repetition priming effects for L1 than L2 can be understood in a number of different ways. Because there are typically larger priming effects for the less dominant language, observing an interaction between language and the magnitude of repetition priming is not a surprising result. However, it is also possible that since naming in L1 was significantly faster in the fourth block than the first (and was not faster in the third block), inhibition of L1 caused by naming in L2 in the first two blocks may have been overcome somewhat by naming the items in L1 in the third block. The RT data alone do not adjudicate between these alternative explanations.

In the analyses of error rates, the main effect of language was significant, $F(1, 32) = 59.62$, $p < 0.001$, indicating that more errors were made in L2 naming overall. The main effect of task order was not significant. However, there was a marginally significant trend for an interaction between language and task order, $F(1, 32) = 3.32$, $p = 0.08$.

ERP Data

Grand average ERPs for naming pictures in Blocks 1, 3, and 4 and topographical maps are shown in Figures 1, 2, 3, and 4. All conditions revealed a similar pattern beginning with a negative peak at approximately 100 ms at frontal and central sites (reversing to a positive peak at posterior sites), consistent with an N100 component. A second negative peak at 150 ms was also observed at central sites. These negative peaks were followed by a P2 peak, maximal slightly after 200 ms. A subsequent negative-going wave was observed to peak around 325 ms, and lasted until about 550 ms after picture onset. This negative component is consistent with the time-course of the N2 component discussed in previous ERP language switching studies (e.g., Jackson et al., 2001; Christoffels et al., 2007) and is hereafter referred to as the N2. This component was followed by a general positivity extending throughout the remainder of the epoch. Overall, the ERPs were more negative when L1 naming followed L2, while the ERPs were more positive when L2 naming followed L1.

Waveforms for the conditions were similar during the earliest part of the epoch, but diverged as early as the P2. On the basis of visual inspection and prior ERP reports of language switching effects, four time windows were selected for statistical analyses. The first time window (250-375 ms after stimulus onset) and the second (375-550 ms) covered the peak of N2, the third (550-700 ms) and the fourth (700-1000 ms) time windows covered the late positivity. Two separate windows were selected for the N2 because it seemed to have two peaks, and two separate windows were evaluated for the late positivity because visual inspection revealed differences in how the effects were revealed earlier versus later.

Comparison of Blocks 1 and 3—For the early part of the N2 component, there were no significant results at the midline, although the interaction between language, order, and electrode site showed a trend towards significance, $F(5, 160) = 2.47$, $p = 0.08$. At lateral sites, the three-way interaction between language, task order, and hemisphere was significant, $F(1,32) = 7.49$, $p < 0.05$. These effects likely reflected the fact that the mean amplitude of the N2 elicited by naming in L1 second was more negative than that elicited by naming in L1 first, while the N2 for naming in L2 second was less negative than that found for naming in L2 first. However, further 2 (language) * 2 (task order) ANOVAs performed over each hemisphere revealed no significant effects.

In the late epoch for the N2, no significant main effects or interactions were revealed in the analyses of the midline or lateral sites.

For the early part of the late positivity, there was a trend towards a main effect of task order at midline sites, $F(1,32) = 3.64$, $p = 0.07$, indicating that the positivity elicited by Group A

(i.e., participants who named in L1 first) tended to be larger than that elicited by Group B. The three-way interaction of language, task order, and electrode sites at midline sites also neared significance, $F(5,160) = 2.80$, $p = 0.06$, likely in part reflecting that naming in L1 first elicited a more positive waveform than naming in L1 second, while naming in L2 first versus second showed the opposite pattern. There were no significant results for the lateral sites in this window.

For the later part of the late positivity (700-1000 ms), the main effect of task order was significant at the midline sites, $F(1,32) = 6.38$, $p < 0.05$, again indicating that participants who named in L1 first (Group A) elicited a larger positivity than participants who named in L2 first (Group B). The two-way interaction between task order and language showed a trend towards significance, $F(1,32) = 3.22$, $p = 0.08$, and the three-way interaction with electrode site was significant, $F(5,160) = 4.53$, $p < 0.05$. Further 2 (language) * 2 (task order) ANOVAs were performed over each electrode to follow up on this interaction. Significant or marginally significant language by task order interactions were found over CPz ($F(1,32) = 5.76$, $p < 0.05$) and Pz ($F(1,32) = 4.02$, $p = 0.05$), with trends over FCz ($F(1,32) = 3.82$, $p = 0.06$), Cz ($F(1,32) = 3.26$, $p = 0.08$). Further independent samples *t* tests at CPz and Pz revealed significant differences between the LPC elicited by naming in L1 first versus naming in L1 second, while there was no difference elicited by naming in L2 first versus naming in L2 second. At the lateral sites, no comparisons reached significance for the later part of the late positivity, although there was a trend towards significance for the main effect of task order, $F(1,32) = 3.23$, $p = 0.08$, consistent with the observation that the waveform elicited by Group A in this window was more positive than that elicited by Group B.

Comparison of Blocks 1 and 4—For the early part of the N2, there was again no significant effect at the midline sites. However, at the lateral sites, the three-way interaction between language, task order, and hemisphere was significant, $F(1,32) = 7.32$, $p < 0.05$, indicating that naming in L1 second elicited a more negative N2 than naming in L1 first, while naming in L2 first elicited a more negative N2 than naming in L2 second. However, further 2 (language) * 2 (task order) ANOVAs performed over each hemisphere did not reach significance.

During the late window of the N2, the main effect of language was significant at midline sites, $F(1,32) = 4.97$, $p < 0.05$, indicating that naming pictures in L1 elicited a larger negativity than naming pictures in L2. There were no significant effects at lateral sites.

For the early part of the late positivity, the main effect of task order was significant at the midline sites, $F(1,32) = 5.83$, $p < 0.05$, indicating that the LPC elicited by Group A was larger than that elicited by Group B. The three-way interaction between language, task order, and electrode site showed a trend towards significance, $F(5,160) = 2.77$, $p = 0.06$, which may have partially reflected the fact that the waveform for naming in L1 first was more positive than for naming in L1 second, while there was an opposite pattern for L2 (i.e., naming in L2 second produced a more positive waveform than naming in L2 first). At the lateral sites in this window, only the main effect of task order was significant, $F(1,32) = 4.92$, $p < 0.05$, indicating that the early part of the LPC elicited by Group A was larger than that for Group B.

For the later part of the late positivity at midline sites, the main effect of task order was significant, $F(1,32) = 6.35$, $p < 0.05$, indicating that the positivity for those naming in L1 first (Group A) was larger than that for those naming in L2 first (Group B). The two-way interaction between language and task order, $F(1,32) = 5.49$, $p < 0.05$, and the three-way interaction between language, task order, and electrode, $F(5,160) = 5.17$, $p < 0.01$, were also

significant. Further 2 (language) * 2 (task order) ANOVAs were performed over each electrode to follow up on the three-way interaction. Significant language * task order interactions were found over Fz ($F(1,32) = 7.15, p < 0.05$), FCz ($F(1,32) = 5.78, p < 0.05$), CPz ($F(1,32) = 6.56, p < 0.05$), and Pz ($F(1,32) = 6.16, p < 0.05$), with a trend at Cz ($F(1,32) = 3.41, p = 0.07$). Further independent samples *t* tests at the sites with significant interactions indicated that the LPCs elicited by naming in L1 first were significantly more positive than those elicited by naming in L1 second, while there were no differences between the LPCs elicited by naming in L2 first versus L2 second. At lateral sites the main effect of task order was significant, $F(1,32) = 5.05, p < 0.05$, indicating that the late part of the positivity elicited by naming in L1 first was larger than that elicited by naming in L2 first. The three-way interaction between language, task order, and electrode showed a trend towards significance, $F(10,320) = 2.35, p = 0.07$, likely because naming in L1 second elicited a less positive waveform than naming in L1 first, while naming in L2 second elicited a more positive waveform than naming in L2 first.

Discussion

In the current study, ERP and behavioral measures were used to determine whether late but relatively proficient Chinese-English bilinguals inhibit the L1 in order to name pictures in the L2. In contrast to most previous studies that have used the language switching paradigm to evaluate local aspects of cognitive control, with trial-to-trial switches, we sought to evaluate the time course of hypothesized inhibition in bilingual language production. Instead of switching the language of production after one or more items within a block, participants completed two entire blocks of naming in one language followed by two blocks of naming of the same pictures in the other language. We found support for the prediction that repetition of pictures across blocks produce priming, but only for the L2, with repeated items showing shorter RTs, and more positive ERPs when naming in L2 followed naming in L1. In contrast, for the L1, there was little evidence of repetition priming in RTs and contrary to the prediction, significantly more negative ERPs when naming in L1 followed naming in L2. Because the pictures were identical across all blocks of the experiment, the results suggest that there is inhibition of the L1 during the planning of spoken words in the L2. When L1 naming is then required, there appears to be an inhibitory component that overrides priming to diminish any substantial facilitation in the behavioral data and to create negativity in the ERP record. As noted earlier, because repetition effects are known to produce facilitatory priming, the results we have reported are likely to be an underestimate of the true magnitude of inhibition when L1 follows L2.

Because the same items were named in both languages and in both orders of naming, the data we have presented do not specifically address the scope of what is inhibited. However, they do suggest inhibitory effects that are long lasting, consistent with a more global pattern of inhibition. Although the ERP effects were somewhat diminished by the fourth block, they persisted into the fourth naming block, after items had already been repeated once and after there had been the opportunity across many trials to recover the L1.

Like the fMRI data reported by Guo et al. (2011), the present ERP data suggest that inhibitory mechanisms may operate beyond the local contexts evaluated in most task switching paradigms, which is consistent with recent reports from the n-2 repetition paradigm in trilinguals (Philipp et al., 2007; Philipp & Koch, 2009). Like some of the early language switching studies (e.g., Meuter & Allport, 1999), and like Christoffels et al.'s (2007) comparisons of mixed versus blocked naming, we observed larger costs to the L1 than the L2. Our results support a claim that, at least for late but relatively proficient bilinguals who are L1 dominant, naming in L2 requires inhibition of the L1, while naming in L1 does not require the same degree of inhibition of the L2. What is striking is that these

results may be observed even over a period of time that should have allowed any transient local inhibitory processes to resolve and in a paradigm where participants have no uncertainty about the language of naming.

The results also extend recent reports of ERP effects related to lexical mechanisms involved in bilingual language production. As in previous studies using the go/no-go task and the language switching paradigm, we found that the N2 component was sensitive to switches even when those switches occurred across blocks rather than from trial to trial and did not require the inhibition of a response (e.g., Christoffels et al., 2007; Jackson et al., 2001; Rodriguez-Fornells et al., 2005; Verhoef et al., 2009). Like the results of Rodriguez-Fornells et al. (2005), which found incongruent trials that had implicit phonological interference elicited a larger N2, the present study also observed an enhanced N2 when bilinguals switched languages. This was also similar to Jackson et al. However, while Jackson et al. found a greater cost for the L2 in their ERP results and a greater cost for the L1 in their behavioral results, we observed greater costs for the L1 in both ERP and behavioral results. The ERP evidence of inhibition may have differed between studies because of key differences in the two paradigms. Jackson et al. used (cued) local switching with a constrained set of items (eight digits), while our study involved switches between blocks and a large number of unique pictures repeated only across the four blocks. Jackson et al. also collapsed across participants with different L2s and different language learning histories, rather than limiting their participant pool to native speakers of one language as we did. Like our results, Christoffels et al. found changes on the N2 during L1 production, but, unlike Jackson et al.'s and our results, they found a larger N2 for nonswitch trials. However, our results are in line with Christoffels et al.'s enhanced N2 for "mixed nonswitch trials" as compared to blocked trials. As in these previous studies, we found an enhanced N2 in situations where inhibitory control mechanisms are presumed to operate. Although it is still controversial whether the N2 itself reflects detection of response conflict or inhibitory control of interference, we believe the N2 can serve as a more general index for cognitive control due to the fact that extant paradigms such as the language switching task may involve both of these two types of potentially inseparable processes.

The current analysis goes beyond other ERP switching studies in our evaluation of effects on the later parts of the epoch. For example, Christoffels et al. and Verhoef et al. (2009) failed to evaluate any effects in the later epoch we describe as a late positivity. They plotted their waveforms only through about 600 ms, probably because the later epoch was contaminated by movement artifacts caused by overt naming without delay, so it is impossible to determine if late effects were present. Jackson et al. (2001), using the delayed naming task also adopted in our study, evaluated their waveforms through the earlier part of the late negativity we analyzed (i.e., through 700 ms) and found enhanced negativity for switch trials, collapsed across languages. In our study this result differed across languages, with later blocks showing more negativity for L1 but the opposite pattern for L2.

Taken together, the present results extend the growing body of evidence that shows that under some circumstances, L1 dominant bilinguals produce sustained inhibition of L1 following speaking in L2. The use of identical items in the current study did not allow us to specify the scope of how narrow or broad the inhibition might be, but it did provide an initial glimpse into its time course. We can ask two questions about the time course. In the ERP data, we can consider how long the observed negativity for L1 lasted within the planning of a single spoken word. Here we see evidence for a long-lasting negativity even within the time frame of a single trial. But perhaps most dramatically in the present study, we observed this same pattern over the course of two blocks of naming in the L1, many trials after the language switch itself occurred. In this sense, the pattern we report appears to

be global in that it persists temporally, even after the speaker has had what might seem to be sufficient time to recover from momentary inhibition of the native language.

The blocked switching paradigm used in the present study is unique in the literature and provides a new way to examine the inhibitory control processes in bilingual language production. However, one might argue that, like the asymmetric switching cost obtained in previous studies using the language switching paradigm, the asymmetric repetition priming for L1 and L2 observed in the present study does not necessarily reflect inhibition of the dominant language, but implies the persisting activation of a previous memory trace as suggested by Philipp et al. (2007) (for a review, see Koch, Gade, Schuch, & Philipp, 2010; See also Monsell, 2003, for a similar viewpoint). Specifically, after naming a picture in one language in the first block, activation of that language carries over and interferes with subsequent naming in the other language, thus requiring more time to retrieve the name of the picture in the target language. Because the less dominant and functionally less frequent L2 may benefit more from an initial picture-language pairing, the dominant L1 may suffer more from the resulting competition during later naming blocks, leading to the observed L1 and L2 asymmetries. The present study cannot rule out this argument. However, given the fact that repetitions have been shown to generate positive shifts in ERP waveforms in a variety of within language and between language paradigms (e.g., Alvarez, Holcomb, & Grainger, 2003; Rugg & Nagy, 1989), in contrast to the negative shifts we observed on the N2 in our study, our results still suggest that our blocked naming task requires an exercise of cognitive control. Furthermore, given the results with the n-2 repetition paradigm and other studies we have carried out, we tend to support the inhibitory control account.

In other recent work, we have reported related evidence of inhibition when L2 speakers are immersed in the L2 environment. Linck et al. (2009) found that performance on a category fluency task was suppressed in the native language for immersed L2 learners relative to learners with similar L2 experience but living in the L1. The learners were all native English speakers with intermediate levels of proficiency in Spanish as the L2. Immersed learners produced fewer words in English than classroom learners, although they were more proficient in English than in Spanish and produced more words overall in English than in Spanish. To investigate the time course of the apparent suppression of the L1 in this context, Gerfen, Tam, McClain, Linck, and Kroll (in preparation) performed a detailed secondary analysis of both the pattern and acoustic properties of the speech produced in the Linck et al. (2009) study. They used the protocol developed by Rohrer, Wixted, Salmon, and Butters (1995) and adopted by Luo, Luk, and Bialystok (2010) and Sandoval, Gollan, Ferreira, and Salmon (2010) to examine cognitive control processes in bilinguals. The question in the secondary analysis was whether inhibition in the immersion environment might have the consequence of creating a brief delay in retrieving the native language but that once production begins, the system is, in effect, back in gear. Gerfen et al. performed a time course analysis in which the 30 sec production interval was segmented into bins to determine whether production in the L1 was reduced for the immersed learners only when they first began to produce category exemplars or whether the reduction in L1 production was maintained even once they had an opportunity to speak. The analysis showed that immersed learners not only produced fewer words overall in English relative to non-immersed learners, but also took longer to begin to speak English, produced fewer words in English across the entire 30 second trial, and had longer inter-response latencies between spoken words in English than classroom-only learners. The learners immersed in Spanish were also less likely than their classroom counterparts to inadvertently use English words when they performed the task in Spanish.

The results of the Gerfen et al. (in preparation) study provide converging evidence for the finding of long-lasting inhibition in production. Like the present findings, the results for

immersed learners in Gerfen et al. suggest a role for extended inhibition in production of the native language. Unlike the present results, the immersion study did not involve the same items across languages and unlike the picture naming task, the category fluency task is under the control of the speaker. The inhibition observed under these conditions in the immersion study suggests that extended inhibition may very well be global in scope as well as time course. However, the L2 learners in the immersion study were less proficient than the bilinguals in the present study and it is possible that less proficient L2 speakers are particularly dependent on these inhibitory control processes (e.g., Costa & Santesteban, 2004; Levy et al., 2007). It will remain for ongoing research to determine how proficiency and dominance in the two languages affect both the scope and time course.

We noted earlier that inhibition has also been reported in comprehension. Jackson et al. (2004) found a different pattern of results in a receptive switching task than in their productive switching task reported in 2001, although switching was still associated with costs. The Linck et al. (2009) immersion study, which reported inhibition of the L1 in verbal fluency, also found evidence for attenuation of L1 activation in a translation recognition task. Immersed learners were less affected than classroom learners by lexical foils in the L1. But that study did not examine the time course in the comprehension task, so we do not know whether the time course of the lexical attenuation would extend beyond the immediate trial. Other recent reports suggest that there is inhibition of competing cross-language alternatives that is resolved within 750 ms following the presentation of a language ambiguous word (e.g., Macizo et al., 2010). Although it is not clear whether the mechanisms of inhibitory control that underlie comprehension and production are the same, the results of the present experiment, together with other converging studies, provide support for the hypothesis that the native language may be inhibited when bilinguals attempt to speak even a single word in their second language. A clear agenda for future research will be to identify the factors that contribute to the observed inhibitory effects and to determine whether all of these effects are genuine inhibition or attenuation that reflect different aspects of language selection in comprehension and production. Recent neuroimaging studies (e.g., Abutalebi et al., 2008) have argued that in production it is the specific requirement to select between competing alternatives in both languages that differentially engage the brain mechanisms responsible for cognitive control. The same requirement to select between the two languages has also been implicated in the recent demonstrations of a bilingual advantage in the realm of executive control (e.g., Bialystok, Craik, Green, & Gollan, 2009). While the causal factors that map language processing to domain-general cognitive mechanisms and their neural basis are as yet unknown, the approach taken in the present study provides a first step towards mapping out the consequences of language selection. In addition to raising issues about the scope and time course of inhibitory control, it is notable that these consequences are largely evidenced in native language production. Contrary to earlier views that proficient bilingualism was a matter of acquiring skill in the L2, our findings, together with others in the recent literature, demonstrate that the native language is responsive to bilingual experience in a manner that suggests far greater plasticity than was previously assumed (e.g., Kroll, Dussias, Bogulski, & Valdes-Kroff, 2012). In this respect, research on bilingualism holds great promise for revealing aspects of language processing that would otherwise be unavailable in the record of monolingual speech.

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- Both languages compete for selection in bilingual language production.
- There is more than a single locus of inhibition of the non-target language.
- Speaking a weaker language requires globally inhibiting the more dominant language.

Figure 1. Grand average ERPs for naming pictures in L1 in Block 1 (Group A), Block 3 (Group B), and Block 4 (Group B) at nine representative electrode sites. Note that negative is plotted up.

Figure 2.

Topographical maps for the distribution of the difference between naming pictures in L1 in different blocks, i.e., Block 3 minus Block 1 (top), and Block 4 minus Block 1 (bottom).

Figure 3. Grand average ERPs for naming pictures in L2 in Block 1 (Group B), Block 3 (Group A), and Block 4 (Group A) at nine representative electrode sites. Note that negative is plotted up.

Figure 4. Topographical maps for the distribution of the difference between naming pictures in L2 in different blocks, i.e., Block 3 minus Block 1 (top), and Block 4 minus Block 1 (bottom).

Table 1

Profile of the Two Groups of Chinese-English Bilinguals on Language Proficiency and Cognitive Measures.

		Group A n = 18	Group B n = 16
Age (years)		21.2 (1.9)	22.2 (4.3)
Time studied L2 (years)		8.9 (1.8)	8.8 (1.5)
L1 proficiency *	reading	8.7 (1.5)	8.3 (1.4)
	writing	8.1 (1.3)	7.6 (1.3)
	speaking	8.4 (1.4)	8.6 (1.1)
	listening	8.6 (1.1)	8.8 (0.9)
L2 proficiency *	reading	6.5 (1.5)	6.3 (0.9)
	writing	6.1 (1.6)	6.3 (1.3)
	speaking	6.5 (1.8)	6.4 (1.8)
	listening	6.4 (1.7)	6.1 (1.7)
Simon effect (ms)		44 (21)	50 (32)
Reading Span (correct recall, %)		54.10 (14.85)	47.89 (14.76)

Note. Values in parentheses represent standard deviations.

* Self-ratings of proficiency are based on a scale of 1-10, where 10 indicates the highest level of fluency.

Table 2
Mean Reaction Times (RT) and Error Rates (ER) for Each Block

		L1 (Chinese)	L2 (English)
RT (ms)	First	1297 _A (250)	1633 _B (351)
	Second	1159 _A (265)	1209 _B (272)
	Third	1218 _B (258)	1335 _A (205)
	Fourth	1112 _B (254)	1029 _A (267)
ER (%)	First	2.08 _A (3.85)	19.79 _B (11.23)
	Second	1.62 _A (3.82)	16.15 _B (9.96)
	Third	2.60 _B (2.08)	14.58 _A (11.28)
	Fourth	1.82 _B (2.62)	13.19 _A (10.81)

Note. Subscripts on the means indicate which group of participants (A or B) contributed the data. Values in parentheses represent standard deviations.