Published in final edited form as:

Ment Lex. 2008 ; 3(3): 349–374. doi:10.1075/ml.3.3.06lin.

Cross-language lexical processes and inhibitory control

Jared A. Linck[a], **Noriko Hoshino**[b], and **Judith F. Kroll**[a]

[a] Department of Psychology, Pennsylvania State University

[b] ESRC Centre for Research on Bilingualism in Theory and Practice, Bangor University

Abstract

Many recent studies demonstrate that both languages are active when bilinguals and second language (L2) learners are reading, listening, or speaking one language only. The parallel activity of the two languages has been hypothesized to create competition that must be resolved. Models of bilingual lexical access have proposed an inhibitory control mechanism to effectively limit attention to the intended language (e.g., Green, 1998). Critically, other recent research suggests that a lifetime of experience as a bilingual negotiating the competition across the two languages confers a set of benefits to cognitive control processes more generally (e.g., Bialystok, Craik, Klein, & Viswanathan, 2004). However, few studies have examined the consequences of individual differences in inhibitory control for performance on language processing tasks. The goal of the present work was to determine whether there is a relation between enhanced executive function and performance for L2 learners and bilinguals on lexical comprehension and production tasks. Data were analyzed from two studies involving a range of language processing tasks, a working memory measure, and also the Simon task, a nonlinguistic measure of inhibitory control. The results demonstrate that greater working memory resources and enhanced inhibitory control are related to a reduction in cross-language activation in a sentence context word naming task and a picture naming task, respectively. Other factors that may be related to inhibitory control are identified. The implications of these results for models of bilingual lexical comprehension and production are discussed.

Research on bilingual language processing suggests that activation spreads within a bilingual's two languages in a language non-specific manner with alternatives in both languages active to some degree. The intention to use one language only does not suffice to restrict activation to one language and does not appear to be restricted to a particular task. The parallel activity of the two languages appears to be manifest in reading, listening and speaking (e.g., Costa, 2005; Spivey & Marian, 1999; Van Heuven, Dijkstra, & Grainger, 1998). A consequence of this parallel activity is that lexical alternatives in the two languages of the bilingual may become available and compete for selection (e.g., Abutalebi et al., 2008; Kroll, Bobb, Misra, & Guo, 2008; but see Costa & Caramazza, 1999, and Finkbeiner, Gollan, & Caramazza, 2006, for arguments against competition for selection). In order to effectively communicate in the desired language, the hypothesized cross-language competition must be resolved.[1] One possible mechanism that has been proposed to aid in this competition resolution is inhibitory control (e.g., Green, 1998; Meuter & Allport, 1999). We begin with a brief review of evidence that suggests that the first language (L1) is inhibited during second language (L2) processing.

Correspondence concerning this article should be addressed to Jared Linck, who is now at the Center for Advanced Study of Language, University of Maryland, PO Box 25, College Park, MD 20742 USA. Phone: 301-226-8879, Fax: 301-226-8811, jlinck@casl.umd.edu.

[1]The alternative to competition for selection assumes that bilinguals acquire the skill to selectively attend to those features of the language environment that make it more likely that one language rather than the other is intended. See Kroll et al. (2008) for arguments against the view that bilinguals are able to exploit cues to language status that would enable a pre-selective mechanism to work in this manner.

Inhibition in Bilingual Language Processing

Meuter and Allport (1999) asked relatively proficient bilinguals to name digits in their L1 or L2, with the desired language indicated by a color cue. The language of naming varied randomly across trials, such that on some trials the language of naming was the same as on the previous trial (termed a *non-switch trial)*, whereas on other trials participants were required to name the digit in the language that was not used on the previous trial and therefore had to switch languages between trials (termed a *switch trial)*. A comparison of the naming latencies in both conditions found that participants took significantly longer to name a digit on switch trials than on non-switch trials. Counterintuitively, the observed switch cost was greater when switching into the more dominant L1 than when switching into the weaker L2. The authors argued that naming in the L2 necessitated inhibition of the more dominant L1. When switching back into the L1, additional time was required to overcome the residual inhibition of the L1, thus leading to the observed asymmetrical switch costs. More recent studies of language switching suggest that the asymmetrical pattern of switch costs is found only for less proficient or strongly L1 dominant bilinguals. Costa and Santesteban (2004) reported evidence suggesting that highly proficient and balanced bilinguals produce a pattern of switch costs that is symmetrical across the two languages. They suggested that increased proficiency is associated with increased skill in language selection such that highly skilled bilinguals no longer require active inhibition of the L1.

L1 inhibition was also evident in a recent study designed to examine language processing within an L2 immersion environment. Linck, Kroll, and Sunderman (2008) compared L2 learners who were immersed in the L2 during a semester abroad with learners who had L2 classroom experience only. Participants performed a translation recognition task (e.g., De Groot, 1992; Sunderman & Kroll, 2006) and a verbal fluency task (e.g., Gollan, Montoya, & Werner, 2002), as well as measures of individual differences in memory resources. In translation recognition, an L2 word and an L1 word are presented and the participant must decide whether the two words are a correct translation pair (e.g., *cara* – *face*). In this study, the word pairs were presented with the L2 word preceding the L1 word, although other studies have also presented the L1 word prior to the L2 word and/ or the two words simultaneously. Critically, among the non-translation pairs were word pairs related in lexical form (e.g., *cara* – *card*), in similarity to the translation (e.g., *cara* – *fact*), or in meaning (e.g., *cara* – *head*), as well as an unrelated control word (e.g., *cara* – *lake*). The difference in reaction times (RTs) between the critical distractor and control trials provides a measure of interference due to the relatedness of the distractor words. Classroom learners suffered moderate amounts of interference in all conditions. In contrast, immersed learners produced semantic interference but no lexical interference for lexical neighbors and reduced interference for words similar to the translation equivalent. The results suggest that in the L2 immersion environment, the L1 is less available. The absence of lexical form interference is consistent with the interpretation that the L1 was inhibited. In the verbal fluency task, participants were presented a category (e.g., *fruits*) and were instructed to produce as many examples of that category as they could within 30 seconds (e.g., "apple, orange, peach…"). Relative to the classroom learners, the immersed learners produced significantly more examples in the L2. Critically, the immersed learners produced significantly fewer examples in their L1, providing further evidence for inhibition of the L1 in the immersion context.

Other research has taken the approach of attempting to experimentally induce inhibition of the L1. Levy, McVeigh, Marful, and Anderson (2007) adapted the retrieval practice paradigm (Anderson, Bjork, & Bjork, 1994) to investigate bilingual memory. Previous research with monolingual participants has shown that retrieving an item from memory (e.g., naming the picture of an apple) induces inhibition of related but nonretrieved items (e.g., orange). Given the high level of relatedness between cross-language translations, it seems feasible that naming an item in one language (e.g., *cara*) might induce such inhibition of its translation (*face*) if the translation is not named. To test this hypothesis, Levy et al. had L2 learners perform a picture naming task, with some pictures named in L1 and others in L2. Participants later recalled the L1 names of all pictures. Repetition facilitation was predicted when pictures were named in L1 at both study and test. In contrast, if naming in the L2 requires inhibition of the more dominant L1 name, it was predicted that recall of these pictures' L1 names at test should be impaired. The results confirmed these predictions, with enhanced recall following repetition and impaired recall for the L1 name of pictures previously named in the L2. A comparison of performance at test with tasks intended to localize the level at which inhibition occurs suggested that it was the phonology of the L1 that was inhibited.

These behavioral data converge nicely with an emerging body of research on the neurocognitive mechanisms underlying language control in bilinguals (e.g., Abutalebi et al., 2008; Abutalebi & Green, 2007). In particular, the prefrontal cortex has been identified as the primary neural region subserving top-down cognitive control in bilingual speech production. In addition, recent studies examining event related potentials (ERPs) in bilinguals have found further evidence that bilingual speech production involves inhibition (Kroll et al., 2008). Taken together, the emerging behavioral and neural data on inhibition lend further empirical support to the inhibitory control account.

Theoretical Claims about Inhibitory Control

Models of bilingual language processing have posited an inhibitory component as one mechanism for resolving competition. Green (1998) proposed the Inhibition Control (IC) model in which competing potential outputs of the lexico-semantic system are inhibited depending on the goals of the speaker. That is, inappropriate responses such as words from the non-target language are inhibited to prevent their production. This top-down inhibition is reactive in nature, suppressing the non-target candidates as they become activated — a claim that has been made elsewhere. In the original Bilingual Interactive Activation (BIA) model of word recognition (Dijkstra & Van Heuven, 1998; Grainger & Dijkstra, 1992), as word representations in one language become activated, they spread activation to a language node which then inhibits all word representations in the other language. However, the activation of the language nodes could be suppressed via top-down control based on the current task demands. It is worth noting that this model also includes bottom-up inhibition based on the input to the lexicon. In particular, activation of competing lexical alternatives is modulated via lateral inhibition between the competing items themselves. However, in the more recent BIA + model (Dijkstra & Van Heuven, 2002), the inhibitory role of the language nodes is rejected, with the task/decision system providing a top-down mechanism of control which integrates the goals of the speaker and other non-linguistic contextual factors to guide lexical selection. Importantly, non-linguistic factors such as task demands or expectations of the bilingual do *not* affect the activation of the word representations within the lexicon (e.g., via inhibition), but rather they modulate the decision criteria that guide selection. Nonetheless, the modulation of activation by top-down inhibitory control is compatible with the architecture and mechanisms of existing models of bilingual language processing, suggesting further theoretical developments of an inhibitory control account are well within reach.

Cognitive Consequences of Bilingualism

If bilingual language control is exerted via the use of inhibitory control, then we might expect to see consequences in other non-linguistic realms of cognition that require inhibitory control. Indeed, there is an emerging body of evidence suggesting that the lifelong experience of maintaining control over two competing languages is in fact related to enhanced executive functioning abilities (e.g., Bialystok et al., 2004). In a collection of studies involving young children and aging adults, early bilinguals have been found to outperform their matched monolingual counterparts on a variety of tasks that require the use of executive functioning (Bialystok et al., 2004; Bialystok, Craik, & Ruocco, 2006; Bialystok, Craik & Ryan, 2006; Bialystok & Shapero, 2005). However, the majority of data on the cognitive benefits of bilingualism come from studies involving young children and the elderly, populations that are known to have restricted memory resources. Any cognitive benefits found with young adult bilinguals tend to be smaller than those found with children or aging bilinguals and/or are found in contexts imposing higher processing demands (e.g., Bialystok, 2006; Bialystok et al., 2004; Bialystok, Craik, & Ruocco, 2006). Recently, Costa, Hernandez, and Sebastián-Gallés (2008) found that relative to their monolingual counterparts, young adult bilinguals demonstrated more efficient executive control in the form of superior conflict resolution on the attentional network task. In addition, Colzato et al. (2008) reported evidence suggesting that bilinguals may develop an enhanced ability to maintain action goals and use these goals to reactively inhibit irrelevant information to reduce conflict. Given that conflict resolution is one particularly important component of executive functioning with respect to bilingual language control, these results are encouraging and suggest that further research is needed to elucidate when and how executive functioning (e.g., inhibitory control) is related to the language experiences of bilinguals. Of note, the bilinguals in the Costa et al. and Colzato et al. studies were early bilinguals who had been immersed in the two languages since childhood. We will return to the issue of whether these effects can also be observed for relatively proficient late bilinguals.

The Current Study

The goal of the current study is to identify linguistic and experiential factors that may be related to the development of inhibitory control. Our approach is to utilize data that have been collected in a number of different studies with young adult bilinguals conducted in our laboratory in which the primary goal was to examine language processing in both the L1 and L2. Because we routinely include a battery of tasks to assess individual differences in working memory and executive function, we are in a position to test a set of hypotheses about the cognitive consequences of bilingualism and about the relation between language processing and inhibitory control.

Hypothesis 1. There is a Bilingual Advantage in Inhibitory Control

Given the bilingual advantages found on executive functioning tasks reviewed above, we expect to find that bilinguals demonstrate greater inhibitory control than monolinguals. If young adult bilinguals reveal the same benefits apparent in the performance of bilingual children and elderly, then they should also outperform monolingual controls on the tasks that require conflict resolution. As noted above, only two past studies have evaluated the cognitive consequences of bilingualism for young adult bilinguals (Colzato et al., 2008; Costa et al., 2008). The present study examines the performance of late bilinguals to further test this hypothesis.

Hypothesis 2. Living in an L2 Immersion Environment is Related to Enhanced Inhibitory Control

Individuals who spend significant amounts of time immersed in the L2 must maintain control over their two languages on a daily basis. The L2 immersion environment in fact has been identified as one learning context that facilitates the development of L1 inhibition in L2 learners (Linck et al., 2008). We might expect, then, that immersion also confers positive cognitive consequences to bilinguals.

Hypothesis 3. More Proficient Bilinguals Exhibit Greater Inhibitory Control

As learners become more proficient in their L2, the level of activation associated with each of their two languages becomes more equivalent, and thus they may suffer increasing amounts of competition between their two languages (Kroll et al., 2008). Learning to handle this cross-language competition might incur benefits to executive functioning, especially when inhibition is used as a means of resolving the competition. Bialystok et al. (2006) reported preliminary empirical data from a dual-task paradigm imposing demands on executive functioning, with unbalanced bilinguals performing better than matched monolinguals but not as well balanced bilinguals. Therefore, we might expect to see a benefit to general inhibitory control in those bilinguals with higher levels of L2 proficiency.

Hypothesis 4. Same-script Bilinguals Have Greater Inhibitory Control than Different-script Bilinguals

Recent research examining the influence of script on language selection suggests that even bilinguals whose two languages have different scripts (e.g., Japanese- English or Chinese-English bilinguals) cannot sufficiently exploit script as a cue to allow early selection of one language (Guo & Peng, 2006; Hoshino & Kroll, 2008). However, when script is visually present during language processing, it appears to modulate the extent of activation across the two languages (Guo & Peng, 2005; Hoshino & Kroll, in preparation). In contrast, bilinguals whose two languages share a common script (e.g., Spanish-English bilinguals) do not have a salient cue available to them when visually processing either language. Having one less useful source of language information available to them, same-script bilinguals might need to further rely upon inhibitory control to help resolve cross-language competition. Thus, we might expect same-script bilinguals to exhibit greater inhibitory control relative to different-script bilinguals.

General Design

As noted above, in all of the ongoing research in our laboratory, we routinely collect data on tasks designed to assess individual differences in cognitive resources. The data we report in the present paper come from the reanalysis of two previous studies that were each designed to examine a different aspect of bilingual lexical processing (Hoshino & Kroll, 2008; Linck et al., 2008). In each study, participants performed a battery of linguistic and cognitive tasks and completed a language history questionnaire. Although the language processing tasks differed in the two studies, all participants performed the Simon task in addition to a measure of working memory capacity. The participants included native English speakers at an intermediate level of learning Spanish (Study 1), Japanese-English and Spanish-English bilinguals (Study 2), and monolingual English speakers (Study 1). Participants were all young adult bilinguals (19–40 yrs.) and were tested in either an L1-dominant or an L2-dominant context. The results of the language processing tasks from both studies have been reported elsewhere (Hoshino & Kroll, 2008; Linck et al., 2008). The current work takes an individual differences analytic approach to examine the relationship between different aspects of language experience (e.g., L2 immersion), inhibitory control, and online measures of L1 and L2 processing.

Simon Task

The primary dependent variable of interest in this study is performance on the Simon task (e.g., Bialystok et al., 2004; Simon & Rudell, 1967). In this task, a series of boxes is presented on screen, one box at a time. The boxes vary both in color (in our studies, red or blue) and location on screen (at fixation, left of fixation, or right of fixation). Participants are instructed to respond based on the color of the box while ignoring its location. Button press responses are made with either the right or left index finger pressing a button on the right or left side of the keyboard, respectively. On *congruent trials*, the box appears on the same side as the correct button response (e.g., a box left of fixation that requires a left hand *tab* key response), and thus the stimulus and response locations match. On *incongruent trials*, the box appears on the opposite side as the correct button response (e.g., a box left of fixation that requires a right hand *backslash* key response). On *central trials*, the box appears at fixation and thus is neither congruent nor incongruent with the correct response location. It is a well-established finding in the cognitive literature on stimulus-response compatibility that response times are longer on incongruent trials relative to congruent trials due to the mismatch between the stimulus location and the response location (e.g., Simon & Rudell, 1967). This difference is referred to as the *Simon effect*, and the magnitude of the Simon effect is interpreted as a reflection of the participant's ability to inhibit the prepotent response cued by the stimulus location. Thus, we use the Simon effect as a non-linguistic measure of inhibitory control.

Other Measures

A working memory (WM) task was included in both studies. This task requires the participant to actively process information while also storing other information in working memory to allow it to be readily available for retrieval. The two studies differed in the nature of the processing component, with the first study involving language processing and the second involving arithmetic processing. Specific details will be provided with each study. In addition, participants completed a language history questionnaire to obtain information regarding their previous experiences with languages and their current language usage.[2]

Study 1: L2 Spanish Learners

Method

Participants—The following analyses were performed on data from native English speakers studying at a US university. The participants included L2 learners of Spanish and a comparison group of English monolinguals. The L2 learners comprised four groups. The *pre-immersion learners* were students taking an intermediate level university language course and preparing to spend a semester abroad. The *immersed learners* included students learning Spanish who were tested in the L2 environment approximately three months into a semester abroad in Spain. The immersed learners lived either with a host family or with college-aged native Spanish speakers and were enrolled in courses taught entirely in Spanish. However, many of them reported having moderate to frequent interactions in English with other immersed students. The *post-immersion learners* were students who had returned from a semester abroad in Spain within the past year and also had enrolled in at least one intermediate level university Spanish language course following their semester abroad. The *classroom learners* were students at a similar level of university language courses as the immersed and post-immersion learners. Importantly, the classroom learners had spent no time abroad. The *monolingual* participants were enrolled in an Introductory Psychology course and had limited exposure to an L2. In order to allow a more meaningful comparison of monolingual participants with the other bilingual learners, any participants from the monolingual group who rated themselves as having moderate levels of proficiency in an L2[3] were excluded from all analyses. This led to the exclusion of thirteen participants, leaving a final total of 28 monolingual participants. See Table 1 for characteristics of each group.

Procedure: Participants performed a battery of language tasks designed to examine various aspects of lexical processing. In addition, two cognitive tasks (reading span and Simon tasks) were administered to measure individual differences in cognitive abilities. We focus our

---

[2]Although slightly different versions of the language history questionnaire were used in Experiments 1 and 2, the contents of the questionnaire were similar (see Tokowicz, Michael, & Kroll, 2004 for a published version of a similar questionnaire).

[3]In this analysis, participants were considered to have a moderate level of L2 proficiency if they rated their proficiency as greater than or equal to 4.0 on a scale from 1 (not proficient) to 10 (highly proficient).

analyses below on the performance data from the two individual difference measures as well as a sentence context word production task using the rapid serial visual presentation technique (RSVP; see Schwartz & Kroll, 2006, for further details; for a description of all other linguistic tasks performed, see Linck, 2005).

Reading span task: To measure individual differences in WM capacity, an adaptation of the Waters and Caplan (1996) reading span task was used. The task is hypothesized to measure cognitive resources available for the processing and storage of information. Participants are required to read sentences and make judgments about their plausibility, while also holding in memory the final word from each sentence in a given block. In the below analyses, WM span is calculated as the number of correctly recalled final words out of 80 possible.

RSVP task: Materials were sampled from a previous study (Schwartz, 2003; Schwartz & Kroll, 2006). Sentences were presented on screen in black font one word at a time at a fixed rate of presentation. A target word in the middle of the sentence was presented in red font and remained on screen until the participant named the word aloud, and naming latencies were recorded. The target words included cognates and non-cognates to examine the influence of cross-language activation on naming. If both languages are activated in parallel even when the sentence appears in one language alone, then like the results of out-of-context word recognition experiments, cognates should be named more quickly than non-cognates (e.g., Schwartz, Kroll, & Diaz, 2007). In addition, sentences were manipulated to provide either high or low semantic constraints for possible target words (e.g., high constraint: "Before playing, the composer first wiped the keys of the *piano* at the beginning of the concert"; low constraint: "When we entered the dining hall we saw the *piano* in the corner of the room"). Previous studies have shown that parallel activation of the two languages is reduced in the context of highly constrained sentence context (e.g., Duyck, Van Assche, Drieghe, & Hartsuiker, 2007; Schwartz & Kroll, 2006; Van Hell, 1998). Each sentence included words from one language only, and the sentences were blocked by language. The immersed learners performed this task in Spanish (L2) first and English (L1) second. However, we will only analyze performance in the L2 sentences in order to examine the extent to which activation of the more dominant L1 influenced naming in the L2 and whether the predicted effect was modulated by individual differences in cognitive resources.

Results and Discussion

Hypothesis 1: There is a Bilingual Advantage in Inhibitory Control—To test the hypothesis that bilinguals have an inhibitory control advantage, the magnitude of the Simon effect was compared between the monolingual participants and all bilingual participants. A preliminary analysis of WM span found significant differences between bilinguals (50.8 words out of 80 possible) and monolinguals (43.5 out of 80), $t(110) = -2.77$, $p = .007$. Thus, WM span differences were controlled for in the analysis of the Simon effect. An Analysis of Covariance (ANCOVA) with WM span entered as a covariate found bilinguals to have a significantly smaller Simon effect relative to monolinguals (34.2 ms vs. 47.7 ms, respectively), $F(1,109) = 5.36$, $p = .022$. That is, after controlling for differences in WM resources, bilinguals showed evidence of superior inhibitory control on the Simon task. The finding of higher WM for bilinguals than monolinguals also replicates a previous study that showed that proficient bilinguals had higher WM span than beginning L2 learners (Kroll, Michael, Tokowicz, & Dufour, 2002).

Hypothesis 2: Living in an L2 Immersion Environment is Related to Enhanced Inhibitory Control—In order to examine the role of the linguistic context in the development of inhibitory control, we compared the immersed learners to the classroom learners. These two groups were closely matched on a variety of cognitive and linguistic measures, including self-rated L1 and L2 proficiency and WM span (all *p*s > .10).[4] An examination of performance on the Simon task found evidence against our hypothesis: classroom learners who had never been in an L2 immersion context showed significantly better inhibitory control relative to the immersed learners with three months of L2 immersion experience. The classroom learners had a significantly smaller Simon effect than the immersed learners (25 ms vs. 43 ms, respectively), $t(49) = -2.54$, $p = .014$.

Hypothesis 3: More Proficient Bilinguals Exhibit Greater Inhibitory Control— Two measures of L2 proficiency were included in the analysis of L2 proficiency and the Simon effect. For the self-reported ratings of L2 proficiency (aggregated across the four skills of reading, writing, speaking and listening), no relationship was found between L2 proficiency and the Simon effect, $r = .018$, $p > .50$. However, contrary to our prediction, greater L2 proficiency was found to be related to worse inhibitory control when using an online measure of L2 proficiency. In particular, a reliable relationship was found between RTs for correct "yes" trials on the translation recognition task (e.g., De Groot, 1992) and the Simon effect, $r = -.199$, $p = .035$. This is a noteworthy relationship given that performance on the translation recognition task provides an online measure of moment-by-moment linguistic processing abilities of these L2 learners.

Immersed Learners' Language Processing Performance—The performance of the immersed learners on the RSVP task was examined in order to ask whether individual differences in inhibitory control and cognitive resources are related to online measures of bilingual language processing. In particular, we were interested in identifying the extent to which inhibitory control and available cognitive resources modulated cross-language activation in a sentence context. Previous research with this task has found that activation can be restricted to one language (as indexed by the lack of cognate facilitation) when the sentence provides a sufficiently rich semantic context (Duyck et al., 2007; Schwartz & Kroll, 2006; Van Hell, 1998). To examine the magnitude of cognate facilitation in high and low constraint sentences, a 2 (high constraint vs. low constraint) × 2 (cognate vs. control) ANOVA was performed on the immersed learners' L2 performance data. The main effect of cognate status approached significance, $F(1,27) = 3.86$, $p = .060$; however, the critical two-way interaction failed to reach significance, $F(1,27) = 2.80$, $p = .106$. A follow-up analysis including RTs on the L2 filler trials as a covariate was performed in order to control for differences in L2 production abilities. This Analysis of Covariance (ANCOVA) found a significant interaction between sentence constraint and cognate status, $F(1,26) = 6.63$, $p = .016$. Post-hoc paired comparisons found that this interaction was due to the presence of significant cognate facilitation in the low constraint condition, $t(27) = -2.31$, $p = .029$, but not in the high constraint condition, $t(27) = -0.98$, $p = .335$. That is, the semantic constraints of the sentence context were sufficient to restrict activation to the L2, replicating Schwartz and Kroll's results with these learners immersed in an L2 environment.

Of particular interest to the analysis of language processing is the relation between the two individual difference measures and cognate facilitation in the naming task. Hierarchical regression analyses were conducted on the magnitude of cognate facilitation for both the high constraint and low constraint sentence conditions. After controlling for RTs on the L2 filler trials, WM span was found to reliably predict cognate facilitation in both conditions (see Table 2 for a summary of hierarchical regression analyses). In both high and low constraint conditions, WM span accounted for a significant amount of variance (20.6% and 18.9%, respectively), such that greater WM resources were related to reduced cognate facilitation.

[4]Classroom learners were on average about nine months older than the immersed learners, $t(49) = -3.76$, $p < .001$. However, the same pattern of results is found when an ANCOVA is performed on the Simon effect data with age entered as a covariate.

That is, immersed learners who had more cognitive resources available were able to restrict the amount of cross-language activation during an in-sentence naming task. Importantly, this was true in both high and low constraint sentences. However, the Simon effect did not reliably predict cognate facilitation in either condition (*p*s > .25). Taken together, these results provide further evidence of the important role of individual differences in executive functioning on bilingual language processing (e.g., Michael & Gollan, 2005), and suggest that future research must continue to elucidate the separable influences of the various components of executive functioning (e.g., Friedman & Miyake, 2004).

The results from this study suggest that the context of learning may play an important role in the development of inhibitory control in bilinguals. The immersed learners were living in a situation where it would be adaptive to enhance control over the L1. However, in the L2 immersion context, there are exogenous cues available to the learner regarding what to inhibit (i.e., the L1), whereas for bilinguals living in an L1-dominant environment, the cues for inhibitory control must come from within given the dearth of external cues. Moreover, L2 proficiency seems to be an important factor for inhibitory control, even within this sample of unbalanced bilingual learners; combined with the recent evidence of bilingual advantages in inhibitory control found with early bilingual children and aging adults (e.g., Bialystok et al., 2004), it is important to consider the case of highly proficient late learners of an L2. The purpose of Study 2 was to test the above hypotheses regarding inhibitory control with a sample of more proficient late bilinguals.

Study 2: Proficient Spanish-English and Japanese-English Bilinguals

Method

Participants—Thirty-four Spanish-English bilinguals and 26 Japanese-English bilinguals who were all L1 dominant but highly proficient in the L2 English were included from Hoshino and Kroll (2008) in the following set of data analyses.[5] Sixteen out of 34 Spanish-English bilinguals were tested in Spain (L1 context) and ten out of 26 Japanese-English bilinguals were tested in Japan (L1 context). The rest of the bilinguals all participated in this study in the US (L2 context). Spanish-English bilinguals and Japanese-English bilinguals were closely matched on age, L1 self-ratings, age of L2 acquisition, amount of time living in English speaking countries, daily usage of L1 and L2, and L2 picture naming latencies and accuracy. The only difference in language background and linguistic measures was that the self-ratings for L2 English proficiency were higher for the Spanish-English than for the Japanese-English bilinguals, $t(58) = 3.22$, $p < .01$. Although this difference in L2 self-ratings could reflect a higher L2 proficiency for Spanish-English bilinguals, more objective on-line proficiency measures such as L2 picture naming latencies and accuracy showed that these two groups of bilinguals were similarly proficient in L2 English. Similarities and differences in the Simon effect and the operation span between the two bilingual groups are discussed below. Characteristics of each bilingual group are summarized in Table 3.[6]

Procedure—Participants performed a picture naming task in their L2 English, followed by two cognitive tasks (Simon and operation span tasks) and a language history questionnaire.

Picture naming task: Pictures were presented on a computer screen one at a time. Participants were asked to name each picture in their L2 English as quickly and accurately as possible. Half of the pictures were cognates and the other half non-cognates that were matched on lexical

[5]One Spanish-English and one Japanese-English bilingual who were older than the age of 40 were excluded in the present analysis.
[6]The original study (Hoshino & Kroll, 2008) was not designed to examine the effect of linguistic context. Therefore, the L1 and L2 context subgroups within each native language group were not as closely matched as were the larger Spanish-English and Japanese-English bilingual groups on some individual difference measures.

variables with the cognates. The cognates were divided into three categories: cognates in English, Spanish, and Japanese, cognates in English and Spanish, and cognates in English and Japanese (see Hoshino & Kroll, 2008, for details). For the purpose of the present paper, we focus our analyses on the data from cognates in English, Spanish, and Japanese, and their non-cognate controls.

Operation span task: An operation span task was used to measure individual differences in cognitive resources. Performance on the operation span task appears to predict the efficiency of language processing as well as reading and speaking span measures but minimizing the contribution of language-specific processing (Turner & Engle, 1989).

In the operation span task, a series of simple arithmetic equations (e.g., (4 * 2) − 2 = 2, (16/2) −5 = 3) were presented on a computer screen one by one, followed by an English word. Participants were asked to solve the arithmetic operations that appeared and to decide whether the presented equation was correct or not as quickly and accurately as possible while remembering the series of presented English words. At certain intervals, the word *RECALL* appeared, followed by a blank screen. At this point, participants were asked to use the keyboard to type all the English words in the set. The materials were taken from Tokowicz, Michael, and Kroll (2004). In the following analyses, operation span was calculated as the number of English words that were recalled correctly for trials in which participants made a judgment on the equation correctly. Note that the highest possible score was 60 in the operation span task, whereas it was 80 in the reading span task in Study 1.

Results and Discussion

Hypothesis 2: Living in an L2 Immersion Environment is Related to Enhanced Inhibitory Control—To examine the relationship between the linguistic context and inhibitory control, we regrouped Spanish-English and Japanese-English bilinguals into bilinguals immersed in the L1 context and those in the L2 context. As mentioned earlier, bilinguals in the L1 context and bilinguals in the L2 context were significantly different in age, L1 and L2 self-ratings, length of living in English speaking countries, daily usage of L1 and L2, and L2 picture naming accuracy (*p*s < .01). Given that differences in self-ratings, immersion experience, and language usage are more likely to result from the context in which bilinguals were living at the time of testing, we included only age and L2 picture naming accuracy as covariates. An analysis of covariance indicated that the difference in the Simon effect between the L1 context and L2 context was not significant after controlling for age and L2 picture naming accuracy, $F(1, 52) = 1.76$, $p > .10$. Although the pattern of the Simon effect (i.e., greater Simon effect for bilinguals in L2 context) was similar to the comparison of classroom learners and immersed learners in Study 1, the difference was not significant in Study 2.

Hypothesis 3: More Proficient Bilinguals Exhibit Greater Inhibitory Control—To test this hypothesis, a regression analysis was performed on the Simon effect with L2 picture naming accuracy as a predictor variable. The analysis showed no relationship between the Simon effect and L2 picture naming accuracy ($F < 1$), suggesting that the Simon effect was not modulated by L2 proficiency among highly proficient bilinguals.

Hypothesis 4: Same-script Bilinguals Have Greater Inhibitory Control than Different-script Bilinguals—As can be seen in Table 3, the mean operation span score was larger for Japanese- English bilinguals than for Spanish-English bilinguals, $t(58) = −2.73$, $p < .01$. It is possible that this difference may reflect cultural differences in arithmetic education between Asian and European/South American countries. Therefore, a hierarchical regression analysis was conducted on the magnitude of Simon effect by entering operation span in the first step and bilingual group in the second step. The analysis showed that there was no difference in the Simon effect between Spanish-English and Japanese-English bilinguals, B = −2.14, β = −.038, $p > .10$.[7]

Relationship Between Inhibitory Control/Working Memory and the Resolution of Cross-language Activation—A critical question of the present paper was to examine the extent to which individual differences in inhibitory control and working memory modulate the degree of cross-language activation. A number of studies on picture naming have shown that bilinguals are faster to name a picture when the picture's name is a cognate translation that has the same meaning and similar phonology across the bilingual's two languages (e.g., *lion – león*) than when the picture's name is a non-cognate translation (e.g., *leaf – hoja*; see, e.g., Costa, Caramazza, & Sebastián-Gallés, 2000; Hoshino & Kroll, 2008; Kroll, Dijkstra, Janssen, & Schriefers, in preparation). The logic of picture naming with cognates and non-cognates is that if both languages are active regardless of the bilingual's intention to speak in one language, then the level of activation is higher for a cognate than for a non-cognate because the shared phonological segments receive activation from both languages, whereas those of the non-cognate receive activation from one language only. The presence of cognate facilitation suggests that the name of the picture in the non-response language is activated to the point where phonology is specified. As described above, in Study 2, we focused on the items that were cognates for both Spanish-English and Japanese-English bilinguals. A 2 (cognate status: cognate vs. non-cognate) × 2 (language group: Spanish-English vs. Japanese-English) mixed ANOVA revealed only the main effect of cognate status was significant, with faster naming latencies for cognate pictures than for non-cognate pictures, $F(1, 58) = 40.24$, $p < .001$. There was no main effect of language group or no interaction (Fs < 1), suggesting that the magnitude of cognate facilitation was similar for the two bilingual groups.

NIH-PA Author Manuscript

To address the question of the relationship between inhibitory control/working memory and the resolution of cross-language activation, in the present study we used the magnitude of cognate facilitation in picture naming as an index of cross-language activation. The magnitude of cognate facilitation was calculated by subtracting the naming latencies for cognates in English, Spanish, and Japanese from the naming latencies for their matched non-cognate controls. Regression analyses were performed on the magnitude of cognate facilitation with Simon effect and operation span as predictors separately because there was collinearity between the Simon effect and the operation span ($r = -.278$, $p < .05$). The regression analyses revealed that 15.8% and 3.1% of the variance in the magnitude of cognate facilitation was accounted for by Simon effect, $F(1, 58) = 10.89$, $p < .01$, and by operation span, $F(1, 58) = 1.85$, $p > .10$, respectively. That is, the smaller the Simon effect was, the smaller the magnitude of cognate facilitation was (B = 2.34, β = .398, $p < .01$). This result indicates that the bilinguals who had better inhibitory control were better able to suppress the activation of lexical candidates in the non-target language during L2 picture naming. Contrary to Study 1, we did not find a reliable relationship between operation span and cognate facilitation. It is possible in production that inhibitory control might play a greater role than working memory. Indeed, a recent study suggests that cognitive resources might not be a critical factor to modulate the degree of cross-language activation in production (Christoffels, De Groot, & Kroll, 2006).

NIH-PA Author Manuscript

[7]We conducted a post-hoc analysis on the Simon data from Spanish-English and Japanese- English bilinguals who were matched on a variety of language background and linguistic measures in another picture naming study (Hoshino & Kroll, in preparation). For this analysis, we sampled only L1 dominant bilinguals who were under the age of 40 from the original study. Because Japanese-English bilinguals had larger operation span than Spanish-English bilinguals, $t(53) = -4.46$, $p < .001$, a hierarchical regression analysis was performed on the Simon effect by entering operation span in the first step and bilingual group in the second step. Unlike the results of Experiment 2, the difference in the Simon effect was significant with a greater effect for Spanish-English bilinguals than for Japanese-English bilinguals even after controlling for the difference in operation span, B =−19.39, β=−.296, $p < .05$. The mixed results may be partly due to the linguistic context. All the participants were tested in the L2 environment in Hoshino and Kroll (in preparation), whereas approximately half of the participants were tested in L1 context in Hoshino and Kroll (2008). As can be seen in Table 3, the difference between Spanish-English and Japanese-English bilinguals appear to be larger in L2 context. In future research, it is important to systematically examine the relationship between inhibitory control and type of bilingualism (same script vs. different script).

General Discussion

In the present analyses, we have investigated a set of preliminary research questions regarding the nature of inhibitory control and its relationship with bilingualism. It is important to note that any conclusions based on these analyses are highly speculative in nature. Additional work is needed before any firm conclusions can be drawn. We now address the four previously stated hypotheses in turn.

Hypothesis 1: There is a Bilingual Advantage in Inhibitory Control

Past research on the cognitive consequences of bilingualism has found evidence of enhanced inhibitory control on a variety of tasks (e.g., Bialystok et al., 2006; Bialystok & Shapero, 2005; Costa et al., 2008). The Simon task data from Study 1 provide further support for this hypothesis, with the bilinguals exhibiting a smaller Simon effect relative to the monolinguals, even after controlling for differences in available working memory resources. It is important to note that the previous studies all involved *early* bilinguals across a variety of ages, including young children (Bialystok & Shapero, 2005), young adults (Costa et al., 2008), and aging adults (Bialystok et al., 2004; Bialystok, Craik & Ryan, 2006). However, to our knowledge, this is the first study of inhibitory control demonstrating a bilingual advantage with a sample of young adult, *late* learners of an L2. That is, even L2 learners with a late age of acquisition may benefit cognitively from learning the L2. It will be important for future research to determine to what extent the cognitive benefits of bilingualism are similar for early and late bilinguals.[8]

Hypothesis 2: Living in an L2 Immersion Environment is Related to Enhanced Inhibitory Control

The data from the current study do not support this hypothesis. In fact, the opposite pattern was found in Study 1, with the immersed learners exhibiting a decrement in inhibitory control relative to the no-immersion classroom learners. Moreover, the more proficient bilinguals of Study 2 did not show any reliable differences, though the immersed bilinguals tended to have reduced inhibitory control relative to the non-immersed bilinguals. It may be that being immersed in an L2 initially induces costs to inhibitory control, but then inhibitory control recovers as the bilingual has more experience controlling the two languages within the L2 environment. More data are needed to provide a direct test of this idea. One interesting avenue of future research would be to more precisely understand whether developmental changes in inhibitory control occur during an extended L2 immersion experience.

Hypothesis 3: More Proficient Bilinguals Exhibit Greater Inhibitory Control

There was no evidence to support this hypothesis; to the contrary, the more proficient learners in Study 1 showed reduced inhibitory control relative to the less proficient learners. This suggests that the enhancement of inhibitory control in bilinguals is not simply a matter of acquiring greater L2 proficiency. It may be that other experiential factors — e.g., the frequency of L1 use in the L2 environment and the frequency of code-switching — may be more crucial to the development of inhibitory control. For example, intrasentential code-switching in naturalistic conversation obeys syntactic constraints in a highly regular fashion (e.g., Myers-Scotton, 2005), suggesting that the speaker must exert some degree of top-down control when switching languages. When the syntactic structures of the target language and the matrix language do not overlap, the speaker must somehow disengage the syntactic structure of the matrix language to allow the successful and often surprisingly smooth transition to the target language. It seems entirely plausible that inhibition may support this shift. It will be important

[8]It will also be critical in future research to determine whether the observed benefits for late bilinguals reflect a self-selection bias for individuals with enhanced cognitive abilities to pursue L2 study. A related issue has been raised about simultaneous translators whose high level of cognitive resources may be either a cause or effect of their translation experience (e.g., Christoffels et al., 2006).

in future research on the cognitive benefits of bilingualism to identify the influential factors and elucidate the nature of their influences on inhibitory control.

Hypothesis 4: Same-script Bilinguals Should Have Greater Inhibitory Control than Different-script Bilinguals

The results of Study 2 showed that there was no difference in inhibitory control between Spanish-English and Japanese-English bilinguals. However, there is an interesting trend to note in the present results. When comparing these two bilingual groups by linguistic context (L1 context vs. L2 context), a group difference starts to emerge for L2 context, but not for L1 context. Contrary to the hypothesis, different-script bilinguals (Japanese-English bilinguals) tended to show greater inhibitory control than same-script bilinguals (Spanish-English bilinguals) in L2 context. This pattern of the data was replicated in participants from Hoshino and Kroll (in preparation) who were all tested in an L2 context. Although the daily usage of L1 and L2 was matched across the two bilingual groups, the frequency of code-switching was not examined and controlled. It is possible that Japanese-English bilinguals may code-switch less frequently than Spanish-English bilinguals because of the linguistic distance of two languages. If so, compared to Spanish- English bilinguals, Japanese-English bilinguals may be inhibiting the non-target language more strongly when using the target language. A recent electrophysiological study indeed suggests that language switching in everyday life appears to affect language control in bilinguals (Christoffels, Firk, & Schiller, 2007). It will be critical in future research to investigate the relationship between inhibitory control and frequency of language switching.

Individual Differences and Language Processing

Another goal of the present paper was to determine whether the degree of cross-language activation was modulated by individual differences in working memory and inhibitory control. The results of Studies 1 and 2 showed that the magnitude of cognate facilitation when reading words in sentence context was modulated by working memory, with a larger span related to less cross-language activation (i.e., less cognate facilitation); in contrast, the magnitude of cognate facilitation in picture naming was modulated instead by inhibitory control, such that a smaller Simon effect was related to less cross-language activation (i.e., less cognate facilitation). These findings suggest that working memory may play a more important role in comprehension whereas inhibitory control may be more critical in production. It seems plausible to assume that comprehension requires individuals to actively maintain information in memory, whereas production stresses the active selection of information, and that working memory and Simon tasks tap into different components of inhibitory control which may be differentially related to language processing. Indeed, there have been recent proposals for clearer distinctions among separable components of inhibitory control (Friedman & Miyake, 2004). However, there are a number of other factors that might have contributed to the observed difference between Study 1 and Study 2.

One possible factor to be considered is the processing demands imposed by the different tasks. The RSVP task analyzed in Study 1 is a sentence task that may be cognitively more demanding than the simple picture naming task in Study 2. It is possible that as the task becomes more demanding, individual differences in working memory may increasingly affect the degree of cross-language activation. If the task demands matter, then individual differences in working memory should predict the magnitude of cognate facilitation in a sentence production task but not in a picture naming task, and there should be no relationship between working memory measures and cognate effects in a simple word recognition task. Kroll et al. (2002) reported that learners with higher working memory span produced a smaller cognate effect in word translation than learners with lower working memory span. In translation, unlike picture naming, both languages are necessarily activated and that dual activation may also impose additional demands in processing that reveal the consequences of individual differences in working memory.

The other possibility is that the number of potential competitors activated during the task differs for the RSVP task and the picture naming task. It is assumed that in picture naming, a number of lexical alternatives that are related to the target candidate are active across the two languages at least for a short period of time. In the RSVP task, the presented target word and lexical neighbors are active in both languages due to the nature of spreading activation during word recognition (e.g., Dijkstra & Van Heuven, 1998). Although multiple lexical candidates are active in both tasks, there may be a difference in the salience of the competitors. In the picture naming task, it is likely that there is one salient competitor — the name of the object in the non-target language. In contrast, in the sentence processing task, multiple competitors are activated in a bottom-up manner, and perhaps those individuals with greater available cognitive resources are better able to reduce the level of activation of these competitors in the absence of available contextual cues (i.e., in low constraint sentences). However, clearly other factors are also at play here, given the fact that we observed the relationship between the working memory measure and the cognate effect for both low *and* high constraint sentences in the RSVP task. If it is simply a matter of the number of salient competitors, we should not have observed such a relationship for high constraint sentences because fewer alternatives should be active and competing in those sentences. It remains for future research to test each of these predictions about the consequences of processing demands and the degree of cross-language activation for revealing the role of individual differences in cognitive resources in resolving cross-language competition. A particularly promising direction for future studies is the context of vocabulary learning that is the focus of this special issue. Because the earliest stages of L2 learning may impose the greatest demands on cognitive resources, particularly with respect to negotiating the activity of the L1, it seems likely that vocabulary learning will reflect the contributions of individual differences in cognitive abilities (see Michael & Gollan, 2005, for a recent review).

Conclusions

This study examined a set of linguistic and experiential factors that may be related to inhibitory control. Extending previous research limited to bilinguals with an early age of acquisition, we found preliminary evidence of cognitive benefits of bilingualism for L2 learners with a later age of acquisition. However, the nature of the influence of other examined factors (immersion experience, L2 proficiency, and script differences) remains unclear. More research is needed to elucidate the relationship between bilingualism and inhibitory control and to further distinguish among the various forms of inhibitory control. It is clear that this is a rich area for future research that will enhance our understanding of the role of individual differences in executive functioning for L2 acquisition and further constrain theories of the cognitive control of language (e.g., Green, 1998).

The present analysis highlights the interconnected, mutually informative nature of research on L2 learning and research on lexicosemantic representation. By examining factors that impact L2 vocabulary learning (e.g., learning context, language similarity, task demands) and their relationship to inhibitory control, the current study provides important data to continue to elucidate the cognitive mechanisms that negotiate cross-language activation at different levels of L2 proficiency. Theoretical advances in research on these mechanisms will serve to enhance our understanding of the fundamental cognitive skills that facilitate the process of L2 vocabulary learning. Similarly, research on L2 learning provides useful information on how the learning process itself has consequences for the cognitive mechanisms that support L2 learning and use. The fusion of research on L2 learning and representation is clearly a promising and exciting line of inquiry for future research.

NIH-PA Author Manuscript
NIH-PA Author Manuscript

Acknowledgments

The writing of this article was supported in part by NSF Grant BCS-0418071 and NIH Grant R56-HD053146 to Judith F. Kroll and by NSF Dissertation Grant BCS-0518814 to Noriko Hoshino and Judith Kroll.

References

Abutalebi J, Annoni JM, Zimine I, Pegna AJ, Seghier ML, Lee-Jahnke H, Lazeyras F, Cappa SF, Khateb A. Language control and lexical competition in bilinguals: An event-related fMRI study. Cerebral Cortex 2008;18:1496–1505. [PubMed: 17947346]

Abutalebi J, Green D. Bilingual language production: The neurocognition of language representation and control. Journal of Neurolinguistics 2007;20:242–275.

Anderson MC, Bjork RA, Bjork EL. Remembering can cause forgetting: Retrieval dynamics in long-term memory. Journal of Experimental Psychology: Learning, Memory and Cognition 1994;20:1063–1087.

Bialystok E. Effect of bilingualism and computer video game experience on the Simon task. Canadian Journal of Experimental Psychology 2006;60:68–79. [PubMed: 16615719]

Bialystok E, Craik FIM, Klein R, Viswanathan M. Bilingualism, aging, and cognitive control: Evidence from the Simon Task. Psychology and Aging 2004;19:290–303. [PubMed: 15222822]

Bialystok E, Craik FIM, Ruocco AC. Dual-modality monitoring in a classification task: The effects of bilingualism and ageing. Quarterly Journal of Experimental Psychology 2006;59:1968–1983.

Bialystok E, Craik FIM, Ryan J. Executive control in a modified antisaccade task: Effects of aging and bilingualism. Journal of Experimental Psychology: Learning, Memory, and Cognition 2006;32:1341–1354.

Bialystok E, Shapero D. Ambiguous benefits: The effect of bilingualism on reversing ambiguous figures. Developmental Science 2005;8:595–604. [PubMed: 16246250]

Christoffels IK, De Groot AMB, Kroll JF. Memory and language skills in simultaneous interpreters: The role of expertise and language proficiency. Journal of Memory and Language 2006;54:324–345.

Christoffels IK, Firk C, Schiller NO. Bilingual language control: An event-related brain potential study. Brain Research 2007;1147:192–208. [PubMed: 17391649]

Colzato LS, Bajo MT, van den Wildenberg W, Paolieri D, Nieuwenhuis S, La Heij W, Hommel B. How does bilingualism improve executive control? A comparison of active and reactive inhibition mechanisms. Journal of Experimental Psychology: Learning, Memory, and Cognition 2008;34:302–312.

Costa, A. Lexical access in bilingual production. In: Kroll, JF.; De Groot, AMB., editors. Handbook of bilingualism: Psycholinguistic approaches. New York: Oxford University Press; 2005. p. 308-325.

Costa A, Caramazza A. Is lexical selection in bilingual speech production language-specific? Further evidence from Spanish-English and English-Spanish bilinguals. Bilingualism: Language and Cognition 1999;2:231–244.

Costa A, Caramazza A, Sebastian-Galles N. The cognate facilitation effect: Implications for the model of lexical access. Journal of Experimental Psychology: Learning, Memory, and Cognition 2000;26:1283–1296.

Costa A, Hernandez M, Sebastián-Gallés N. Bilingualism aids conflict resolution: Evidence from the ANT task. Cognition 2008;106:59–86. [PubMed: 17275801]

Costa A, Santesteban M. Lexical access in bilingual speech production: Evidence from language switching in highly proficient bilinguals and L2 learners. Journal of Memory and Language 2004;50:491–511.

De Groot AMB. Determinants of word translation. Journal of Experimental Psychology: Learning, Memory, and Cognition 1992;18:1001–1018.

Dijkstra, A.; Van Heuven, WJB. The BIA model and bilingual word recognition. In: Grainger, J.; Jacobs, AM., editors. Localist connectionist approaches to human cognition. Mahwah, NJ: Lawrence Erlbaum Associates; 1998. p. 189-225.

Dijkstra A, Van Heuven WJB. The architecture of the bilingual word recognition system: From identification to decision. Bilingualism: Language and Cognition 2002;5:175–197.

Duyck W, Van Assche E, Drieghe D, Hartsuiker RJ. Visual word recognition by bilinguals in a sentence context: Evidence for nonselective access. Journal of Experimental Psychology: Learning, Memory, and Cognition 2007;33:663–679.

Finkbeiner M, Gollan T, Caramazza A. Bilingual lexical access: What's the (hard) problem? Bilingualism: Language and Cognition 2006;9:153–166.

Friedman NP, Miyake A. The relations among inhibition and interference control functions: A latent-variable analysis. Journal of Experimental Psychology: General 2004;133:101–135. [PubMed: 14979754]

Gollan TH, Montoya RI, Werner GA. Semantic and letter fluency in Spanish- English bilinguals. Neuropsychology 2002;16:562–576. [PubMed: 12382994]

Grainger, J.; Dijkstra, T. On the representation and use of language information in bilinguals. In: Harris, RJ., editor. Cognitive processing in bilinguals. Oxford: North-Holland; 1992. p. 207-220.

Green D. Mental control of the bilingual lexico-semantic system. Bilingualism: Language and Cognition 1998;1:67–81.

Guo, T.; Peng, D. Was the native language activated during the production of the second language: an ERP study with unskilled Chinese-English bilinguals. Poster presented at the Annual Meeting of the Cognitive Neuroscience Society; New York, New York. 2005 Apr.

Guo T, Peng D. ERP evidence for parallel activation of two languages in bilingual speech production. NeuroReport 2006;17:1757–1760. [PubMed: 17164659]

Hoshino N, Kroll JF. The role of script in bilingual word production: Is language specific access possible?. (in preparation)

Hoshino N, Kroll JF. Cognate effects in picture naming: Does cross-language activation survive a change of script? Cognition 2008;106:501–511. [PubMed: 17367774]

Kroll JF, Bobb SC, Misra M, Guo T. Language selection in bilingual speech: Evidence for inhibitory processes. Acta Psychologica 2008;128:416–430. [PubMed: 18358449]

Kroll JF, Michael E, Tokowicz N, Dufour R. The development of lexical fluency in a second language. Second Language Research 2002;18:137–171.

Kroll JF, Dijkstra A, Janssen N, Schriefers H. Selecting the language in which to speak: Experiments on lexical access in bilingual production. (in preparation)

Levy BJ, McVeigh ND, Marful A, Anderson MC. Inhibiting your native language: The role of retrieval-induced forgetting during second language acquisition. Psychological Science 2007;18:29–34. [PubMed: 17362374]

Linck, JA. Unpublished master's thesis. Pennsylvania State University; University Park, PA: 2005. Language and cognitive processing in a study abroad context.

Linck JA, Kroll JF, Sunderman G. Losing access to the native language while immersed in a second language: Evidence for the role of inhibition in second language learning. 2008Manuscript submitted for publication

Meuter RFI, Allport A. Bilingual language switching in naming: asymmetrical costs of language selection. Journal of Memory and Language 1999;40:25–40.

Michael, E.; Gollan, TH. Being and becoming bilingual: Individual differences and consequences for language production. In: Kroll, JF.; De Groot, AMB., editors. Handbook of bilingualism: Psycholinguistic approaches. New York: Oxford University Press; 2005. p. 389-407.

Myers-Scotton, C. Supporting a differential access hypothesis: Code switching and other contact data. In: Kroll, JF.; De Groot, AMB., editors. Handbook of bilingualism: Psycholinguistic approaches. New York: Oxford University Press; 2005. p. 326-348.

Schwartz, AI. Unpublished doctoral dissertation. The Pennsylvania State University; University Park, PA: 2003. The nature of cross-language lexical activation in sentence context: A psycholinguistic investigation.

Schwartz AI, Kroll JF. Bilingual lexical activation in sentence context. Journal of Memory and Language 2006;55:197–212.

Schwartz AI, Kroll JF, Diaz M. Reading words in Spanish and English: Mapping orthography to phonology in two languages. Language and Cognitive Processes 2007;22:106–129.

Simon JR, Rudell AP. Auditory S-R compatibility: The effect of an irrelevant cue on information processing. Journal of Applied Psychology 1967;51:300–304. [PubMed: 6045637]

Spivey MJ, Marian V. Cross talk between native and second languages: Partial activation of an irrelevant lexicon. Psychological Science 1999;10:281–284.

Sunderman G, Kroll JF. First language activation during second language lexical processing: An investigation of lexical form, meaning, and grammatical class. Studies in Second Language Acquisition 2006;32:387–422.

Tokowicz N, Michael E, Kroll JF. The role of study-abroad experience and working- memory capacity in the types of errors made during translation. Bilingualism: Language and Cognition 2004;7:255–272.

Turner ML, Engle RW. Is working memory capacity task dependent? Journal of Memory and Language 1989;28:127–154.

Van Hell, JG. Unpublished dissertation. University of Amsterdam; Amsterdam, The Netherlands: 1998. Cross-language processing and bilingual memory organization.

Van Heuven WJB, Dijkstra T, Grainger J. Orthographic neighborhood effects in bilingual word recognition. Journal of Memory and Language 1998;39:458–483.

Waters GS, Caplan D. The measurement of verbal working memory capacity and its relation to reading comprehension. The Quarterly Journal of Experimental Psychology A: Human Experimental Psychology 1996;49A:51–79.

NIH-PA Author Manuscript

NIH-PA Author Manuscript

Table 1

Group Characteristics of the Participants in Study 1

Variable	Participant group				
	Pre-Imm[a]	**Imm**[b]	**Post-Imm**[c]	**Classroom**[d]	**Monolingual**[e]
Age[f]	20.0	20.5	21.3	21.3	19.5
L2 age of acquisition[f]	14.0	14.6	15.2	14.3	16.0[j]
Semesters of Spanish classes	3.8	4.1	5.2	5.3	0.8
Reading span total[g]	48.6	49.5	46.4	48.9	44.3
Simon effect[h]	37.5	43.2	35.3	25.1	43.7
L1 self-rated proficiency[i]					
Reading	9.5	9.4	9.7	9.6	9.1
Writing	9.4	9.0	9.5	9.4	8.9
Speaking	9.8	9.6	9.8	9.7	9.3
Listening	10.0	9.7	9.7	9.2	9.4
L2 self-rated proficiency[i]					
Reading	5.7	6.4	6.1	6.8	4.6[j]
Writing	5.5	6.2	6.0	6.8	4.3[j]
Speaking	4.5	6.1	5.8	6.0	3.7[j]
Listening	5.9	7.3	6.4	6.8	4.3[j]

Note. Imm = Immersion. L1 = first language. L2 = second language.

[a] n = 20.

[b] n = 28.

[c] n = 50.

[d] n = 23.

[e] n = 41.

[f] Reported in years.

[g] Number of correctly recalled words out of 80 possible.

[h] Amount of interference due to mismatch of stimulus and response locations, reported in milliseconds.

[i] Ratings were made on a 10-point scale ranging from 1 (*not proficient*) to 10 (*highly proficient*).

[j] Values for 22 participants who reported having any knowledge of an L2.

Table 2

Summary of Hierarchical Regression Analyses for Variables Predicting the Magnitude of Cognate Facilitation in Low Constraint and High Constraint Sentence Conditions (N = 27)

	Variable	B	β
Low Constraint Sentences			
Step 1	Filler trial RTs	0.22	0.44*
Step 2	Filler trial RTs	0.22	0.45**
	WM span	−3.09	−0.45**
High Constraint Sentences			
Step 1	Filler trial RTs	−0.01	−0.02
Step 2	Filler trial RTs	−0.01	−0.01
	WM span	−2.48	−0.43*

Note. RT = reaction time. WM = working memory. For low constraint sentences, R^2 = .194 for Step 1 (p = .021); ΔR^2 = .206 for Step 2 (p = .008). For high constraint sentences, R^2 = .001 for Step 1 (*ns*); ΔR^2 = .189 for Step 2 (p = .027).

* $p < .05$.

** $p < .01$.

Table 3

Characteristics of Participants in Study 2

	Spanish-English (n = 34)		Japanese-English (n = 26)	
	L1 context	L2 context	L1 context	L2 context
Age [a]	23.2 (2.2)	25.7 (4.4)	21.3 (2.6)	28.2 (6.5)
L2 age of acquisition[a]	10.3 (1.9)	10.7 (3.9)	9.0 (4.5)	10.7 (3.6)
L1 self-rated proficiency[b]	8.5 (0.9)	9.8 (0.3)	8.0 (1.9)	9.2 (0.9)
L2 self-rated proficiency[b]	7.1 (1.1)	8.4 (1.1)	5.7 (1.2)	7.0 (2.0)
Length of L2 immersion[c]	8.3 (4.2)	47.7 (28.9)	25.3 (38.2)	53.7 (38.5)
Daily L1 usage (%)	80.0 (12.6)	38.3 (24.4)	92.0 (4.8)	24.7 (24.3)
Daily L2 usage (%)	25.0 (18.0)	58.3 (25.0)	12.0 (8.2)	69.1 (24.8)
Simon effect[d]	26.2 (31.8)	46.7 (24.7)	25.4 (12.5)	32.7 (31.9)
Operation span total[e]	30.6 (10.8)	33.2 (10.7)	38.2 (4.7)	38.6 (7.8)
Overall picture naming latencies[d]	1253 (167)	1130 (194)	1195 (203)	1163 (172)
Overall picture naming accuracy (%)	67.5 (13.3)	81.3 (7.5)	70.1 (15.7)	82.1 (10.3)

Note. L1 = first language. L2 = second language. Standard deviations are in parentheses. These data include all but two participants from the original participant groups reported in Hoshino and Kroll (2008) and have been further divided into those bilinguals living in an L1 vs. L2 context for the purposes of the present study.

[a]Reported in years.

[b]Ratings were made on a 10-point scale ranging from 1 (*not proficient*) to 10 (*highly proficient*).

[c]Reported in months.

[d]Reported in milliseconds.

[e]Number of correctly recalled words out of 60.