Examining the role of inhibitory control in bilingual language switching

Alison R. Shell (ashell@umd.edu)
Department of Psychology, University of Maryland, Biology/Psychology Building
College Park, MD, 20742 USA
Jared A. Linck (jlinck@umd.edu)
University of Maryland Center for Advanced Study of Language, 7005 52nd Avenue
College Park, MD 20742 USA
L. Robert Slevc (slevc@umd.edu)
Department of Psychology, University of Maryland, Biology/Psychology Building
College Park, MD 20742 USA

Abstract

Bilingual language production is widely believed to be a competitive process. Bilinguals may manage this competition by relying on inhibiting one language while speaking in the other. However, it remains unclear if this process relies on domain general inhibitory mechanisms, and, if so, when and where during language production inhibitory control is applied. The current study investigates these issues by experimentally manipulating demand on inhibitory control using a picture word interference task during a language switching paradigm. Switching costs were not exacerbated when inhibitory control was taxed; in fact language switching was *less* costly during inhibition-demanding trials. These findings do not support the idea that inhibitory control mechanisms underlie language switching and suggest that language switching and the resolution of within-language lexical competition do not share inhibitory resources.

Keywords: bilingualism; inhibitory control; word production; language switching

Introduction

By most models of word production (e.g., Levelt, Roelofs, & Meyer, 1999), word production starts with a concept, from which activation spreads to an array of lexical items (*lemmas*), which carry semantic and syntactic information without word-form information. As activation spreads to the target lemma and those sharing semantic properties with the target, lexical selection must overcome the influence of competing lemmas; accordingly, selection is generally agreed to be a competitive process (Ferreira, 2010).

For bilinguals, lexical selection not only requires overcoming lexical competition from semantically *similar* items, but also from semantically *identical* items in another language. Cross language facilitation and interference effects show that bilinguals' multiple languages are active at the point of selection (e.g., Kroll, Bobb & Wodniecka, 2006), and thus bilinguals must overcome both within- and between-language competition (e.g., Gollan & Silverberg, 2001).

This additional competition from the non-target language presumably needs to be resolved in order to successfully produce a target lexical item. How speakers do this is still unsettled, however, an influential model proposes that bilinguals use domain-general inhibitory control mechanisms to suppress the non-target language (Green, 1998).

Much of the experimental evidence that inhibitory control is involved in bilingual language control comes from language-switching tasks that require a speaker to switch between languages while naming items as indicated by a cue. Thus trials involve both staying within a language (stay trials), and switching from one language to the other (switch trials). The costs associated with switching (increased reaction time on switch vs. stay trials; cf. switching costs outside of the linguistic domain; Monsell, 2003) are, counter-intuitively, often larger when switching from L2 to L1 than from L1 to L2 (e.g., Meuter & Allport, 1999), which may reflect having to overcome residual inhibition of the more dominant L1. Note, however, these asymmetries are not always found and it is unclear how much about the underlying switching processes can be gleaned from such asymmetries alone (e.g., Bobb & Wodnieka, 2013)

Furthermore, not all bilinguals show such asymmetric switch costs, leading to claims that inhibition is not necessarily required for language control. For instance, Costa and Santesteban (2004) demonstrate that while bilinguals with a dominant L1 show asymmetrical switch costs, balanced bilinguals (who are equally proficient in L1 and L2) fail to show switch cost asymmetries, even when switching between their dominant L1 and a third language (L3) in which they are relatively unskilled. This fits with other evidence suggesting that bilingual lexical selection is not a competitive process. For example, Costa, Miozzo, and Caramazza (1999) found that in a picture word interference task, the expected effects of the distractor word on target picture naming (i.e., semantic interference and phonological facilitation) occurred when the word was presented in the target language, but also in the non-target language. These findings suggest that while both languages are in fact activated, they do not necessarily compete for selection.

Bloem and La Heij (2003) take this even further, suggesting a language specific account of lexical access without competition at the lexical level. Based on findings that related words hindered naming in a translation task, but related *pictures facilitated* translation, they propose that competition is resolved at the earliest stage of production (the conceptual level), that only the target concept is lexicalized, and therefore lexical competition, as has been discussed, does not occur. (Note that their theory does account for the effect of semantic interference in PWI tasks, proposing that interference occurs due to spreading activation from target to related items as a by-product of the lexicalization process.)

On the other hand, other findings do support an important role of inhibitory control in bilingual switching. Much of this comes from correlation between language switching costs and performance on other inhibitory control tasks. That is, bilinguals with higher scores on domain-general inhibitory control tasks tend to perform better on language switching tasks (e.g. Linck, Schwieter, & Sunderman, 2012). Another type of, albeit controversial, support for the role of domain-general inhibitory control in bilingual language production comes from findings that bilinguals' lifetime of practicing inhibitory control in guiding language use may *transfer* to improved performance in domain-general attention and inhibitory control tasks ("the bilingual advantage," e.g., Abutalebi et al., 2012; Bialystok, 1999; but see Papp & Greenberg, 2013).

As such, the support for both cross-language lexical competition and for the role of inhibitory control in resolving this competition is mixed, and often based on correlational evidence, which is subject to alternative explanations (e.g. differences in education, motivation, etc.). The goal of the current study is thus to clarify the role of inhibitory control in bilingual language production by experimentally manipulating the availability of inhibitory control (via lexical competition) during a bilingual production task. If bilingual production does in fact require the same inhibitory control mechanisms involved in resolving lexical competition, it should be subject to the limited capacity of these resources. That is, a concurrent task that shares resources with language selection should interact with a bilingual production task by reducing the ability to deal with the language conflict. Though this effect should occur on all production trials, it should be particularly pronounced on a language switch (i.e. over-additive) if additional control is, in fact, needed in order to switch into the new language. If, however, these tasks do not rely on shared resources, there should be no interaction.

Current Experiment

The current study manipulated inhibitory control during a language switch task using the well-studied picture word interference (PWI) paradigm, which manipulates the level of competition in picture naming by adjusting the relationship between target pictures and concurrently presented distractors. Specifically, picture naming is slowed when distractor words (presented either aurally or superimposed in print) are semantically related to the pictured item (Aristei & Rahman, 2013; Schriefers, Meyer & Levelt, 1990). Because a lexical concept activates not only its own lemma but also semantically similar lemmas, a semantically similar distractor that adds additional activation to a competing lemma can increase lexical competition and the need for inhibitory control. This semantic interference only occurs when the distractor is timed to appear at or just before the picture onset, suggesting that semantic interference occurs early in the process of production, that is, during lemma selection. In the current study, the relation of the distractor word to the target picture (related, unrelated, or neutral) was manipulated during a language-switching paradigm to vary demand on inhibitory control during language switching.

The aim of the current study is to examine the role of domain-general control mechanisms on language switching. The PWI paradigm involves control of linguistic representations, and therefore might be taken to reflect language-specific, rather than domain-general mechanisms. However, while both tasks do rely on lexical selection and likely involve some shared processes, note that the PWI task appears to involve general inhibitory control mechanisms; for example, semantic interference in PWI involves brain regions classically associated with conflict/cognitive control across domains (see de Zubricaray Wilson, McMahon & Muthiah, 2001). Thus, interactions of language switching with PWI interference would likely reflect shared reliance on domain general cognitive control mechanisms.

Method

Participants Thirty-two native English-speaking adults with intermediate proficiency in Spanish (currently or recently having taken intermediate to upper level college Spanish courses) were recruited from the University of Maryland and paid $10 for their participation. These qualifications were assessed with a shortened version of Language Experience and Proficiency Questionnaire (LEAP-Q; Marian, Blumenfeld, & Kaushanskaya, 2007). One participant was excluded from analysis for not meeting the requirement of being a native English speaker.

Materials The target pictures, sixteen black and white drawn images from the International Picture Naming Project (IPNP) database (Szekely et al., 2004), were chosen to be commonly known to intermediate Spanish learners, to avoid cognate names in Spanish and English, and to meet the requirements of the distractor words, as described below.

Trials were set up in triads by language (L1 and L2), with a switch into the language (switch), a stay trial following the switch (stay1) and a second stay (stay2). Lists were created so that each picture showed up equally in each language, and equally in the related and unrelated distractor conditions (described below). Additionally, each picture showed up equally in each of the switch, stay1, and stay2 positions in each language, and each switch trial was followed equally often by a related or unrelated stay trial. Finally, to reduce repetition-priming effects, a picture in a switch trial was never repeated in the following stay1 trial. Note that all trials were pseudo-randomized, with the above constraints, per participant, as to reduce order effects.

All distractor strings were presented in capital letters, in red size 24 Helvetica font, in the center of the picture stimuli to make the string highly visible. Related distractor words were selected from the online WordNet database (Miller, 1995), to be a non-cognate sister term of the target picture item- that is, sharing a hypernym (e.g., "pet" for "cat" and "dog") with the target item (Schriefers et al., 1990) and to have high frequency, as to ensure familiarity for participants. Unrelated distractor words were chosen to be non-cognates, matched in frequency and number of syllables in both Spanish and English, and to be minimally related to the target (e.g., Target: "COW" / "VACA", Related: "HORSE" / "CABALLO", Unrelated: "RING" / "ANILLO"). Neutral "distractors" appeared during the second stay trials (stay2 trials) and acted as a resetting trial before the switch. These neutral "distractors" were a string of "#"'s, which matched the number of characters of the unrelated distractor in the target language to match in terms of visual distraction, but remove potential for any lexical competition with the target word. For example, the neutral distractor for "VACA" ("ANILLO") was "######".

Procedure The experiment was administered using PsyScope X (Build 57; Bonatti, n.d.), and vocal responses and voice onset times were digitally recorded with a head-mounted microphone connected to an IOlab response box. The microphone sensitivity was calibrated for each participant at the start of the session.

A set of practice trials preceded the full experiment to ensure comfort with each component before completing the combined task. To begin, participants were presented with the 32 distractor items in a pre-determined randomized order for translation from Spanish to English. Each item was presented in capital letters, in size 24 black Helvetica font for translation into English. Upon response the correct response appeared below the picture as feedback before the participant could move on to the next trial. The list appeared two times in the same order, to ensure the participant was comfortable with the distractor words and their meanings. Participants were informed that they would be tested on these words at the end of the experiment and encouraged to learn any words they did not yet know. If they received below 75% accuracy, they went through the translation process in the same order a second time. At this point all participants successfully were able to translate with at least 75% accuracy; as such each participant translated each item a maximum of four times.

Participants then practiced naming the 16 pictures, first in English, and then in Spanish, in the same pre-randomized order for both language blocks, to ensure name agreement. In the English block, each picture appeared with a square around the picture, as a cue to name the item in English while in the Spanish block the pictures appeared with a circle around the picture. Again, upon response, the correct item name appeared below the picture as feedback before the participant could move on to the next trial.

Each participant practiced switching between naming three items in Spanish followed by three items in English, each picture appearing with its corresponding language cue. These items were randomly selected from the complete list of items for a total of 12 trials. Before each trial, a fixation-cross appeared in the center of the screen for 1000ms, and the onset of each picture was delayed 500ms after the fixation disappeared. This ISI was chosen to give ample time between trials to reduce interference from errors made on previous trials. The participant practiced naming the pictures in the cued language, which disappeared when their naming response was detected.

Participants then had 12 randomly selected practice trials with the complete task; switching between languages with the same parameters as the switch-only trials, but with a distractor word superimposed on the center of the pictured item. Participants were instructed to name the pictures and to ignore the distractor word. Finally, participants began the experimental portion of the combined task, which consisted of 384 trials with a scheduled, self-timed break halfway through. See Figure 1 for a schematic of the task design.

After completion of the task, the participants were given an untimed vocabulary test where all 32 Spanish distractor items were listed, in a pre-determined randomized order, for translation into English. Finally, the participants completed the shortened LEAP-Q (Marian et al., 2007).

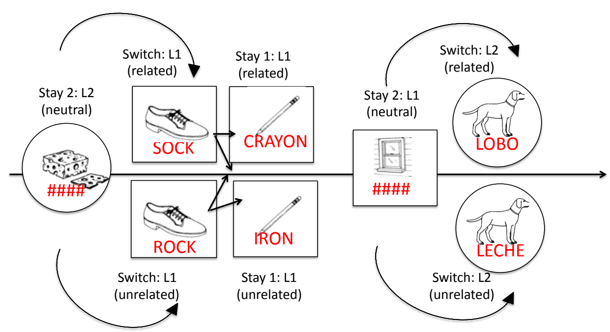

Figure 1: Task schematic of the PWI-language switch paradigm. Language cues are represented by square (L1) and circle (L2) around items. Example distractor words are shown in red.

Design and Analysis Voice key response times were log transformed and analyzed using mixed effects models implemented with the lme4 package (version 1.1-7 Bates, Maechler, Bolker & Walker, 2014) in the statistical software R version 3.1.1 (R Core Team, 2014).

Note that stay2 trials–the neutral fillers–were excluded from analyses, therefore all further discussion of stay trials refers to stay1; correspondingly, distractor conditions are either related or unrelated, as neutral distractors only occurred on stay2 trials. Switch condition (switch or stay language trial) and distractor relatedness (related or unrelated) were entered as fixed effects using orthogonal contrast coding. For response time analyses, the maximal random effects structure was included for both participants and items (pictures), however only the fixed effects will be reported here, as these were the effects of theoretical interest. Because the lmer function does not calculate *p*-value for models with random-effect slopes, in part due to difficulty calculating degrees of freedom, *t*-values with an absolute value greater than 2 were considered to indicate a significant effect (Gelman & Hill, 2007). The primary effect of interest was also evaluated with a chi-square test, based on a single degree of freedom model comparison.

All trials with naming errors (349, 2.9% of trials) and all voice key errors (57, 0.5% of all trials) were removed from the response time data analysis. Additionally, for each participant, any trials in either English or Spanish for which the distractor item was not accurately translated on the vocabulary quiz was removed from analysis (621 trials, 5.4% of accurate naming trials). The most extreme 3% of values (trials with RTs above the 98.5 percentile and below the 1.5 percentile) from the accurate dataset were excluded. Following this, RTs greater than 2 standard deviations from each subject's mean (530 trials, 5.04%) were removed from analysis. In total, these criteria led to the exclusion of 1062 trials (8.9% of total trials).

Accuracy data were analyzed over all trials (removing only those items that had not been accurately translated on the vocabulary quiz) using logistic mixed effects models. Because the accuracy data included very few errors, the fully specified random effects models were unable to converge. Therefore for the accuracy analyses the random intercept models are reported.

Results

As shown in Figure 2, naming was slower in switch than stay trials (a main effect of switch condition: *b* = 0.075, SE = 0.010, *t* = 7.89), showing the expected language switching cost. Additionally, naming was slower when pictures appeared with a related distractor word compared with an unrelated word (a main effect of relatedness: *b* = 0.025, SE = 0.007, *t* = 3.38), showing an expected PWI semantic interference effect. Language (L1/L2) did not participate in any interactions, however switch condition and relatedness did interact. Surprisingly, this interaction was under-additive (*b* = -0.027, SE = 0.013, *t* = -2.18); that is, the effect of a language switch was *smaller* when the switch trial appeared with a related distractor compared with an unrelated distractor. These findings clearly do not support the original predictions of an over-additive interaction. This switching by relatedness interaction was further assessed by comparing an interactive 2x2 model (switch condition by relatedness) with a reduced model that included only additive fixed-effects. A likelihood ratio test confirmed a better fit for the interactive model ($\chi^2_{(1)} = .42$, $p < .05$).

Error rates showed a similar pattern of results, with naming responses on switch trials being 2.54% less accurate than on stay trials (*b* = 1.27, SE = 0.027, *z* = -4.68) and 1.48% less accurate when paired with related compared to unrelated distractors (*b* = -0.75, SE = 0.029, *z* = -2.58). While there was an additional interaction between switch condition and language, with increased errors on L1 switches (*b* = 1.01, SE = 0.45, *z* = 2.26), reflecting a tendency to incorrectly remain in the L2 rather than switch, there was no interaction between switch condition and relatedness (*b* = 0.39, SE = 0.34, *z* = 1.15).

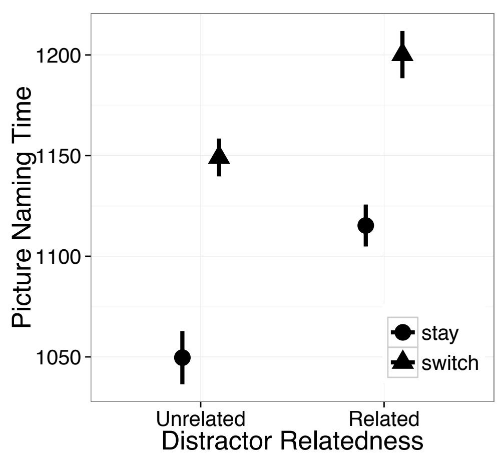

Figure 2: Picture naming RT (ms), as a function of the language switch condition (stay or switch) and the picture-word relatedness in the concurrent PWI task (unrelated or related). Plotted data are means of subject means. Error bars indicate standard error of the mean.

Discussion

This study sought to more precisely define the role of inhibitory control in resolving competition in bilingual lexical access. This was investigated within a limited-resource framework by manipulating the demands on inhibitory control via semantic relatedness in a picture-word interference (PWI) paradigm during bilingual language switching. According to the inhibitory control model (Green, 1998), bilingual speech production requires inhibition to overcome competition from the non-target language and produce the target language. Therefore, in a switch trial, where this inhibitory control is required, a competition-inducing distractor word should tax inhibitory control and therefore interfere with successful inhibition of the non-target language. That is, the model predicts that PWI-induced conflict should increase switch costs. The results show a main effect of switching (switch cost) and main effect of distractor relatedness (PWI effect). While there was, in fact, an interaction between switch condition and relatedness, the interaction was *under-additive,* wherein switch costs were smaller during related trials than unrelated trials. As such, the prediction of increased switch costs during related trials was clearly not supported.

The strongest interpretation of these results is that language switching does not rely on inhibitory control, at least as is required to overcome semantic interference in the PWI paradigm. That is, these results might suggest that this specific type of lexical inhibition is not required for the language switch task, and that the inhibitory control model as it stands is not supported. These findings are congruent with other models of bilingual production that focus on activation, rather than inhibition, to promote the appropriate lexical item. For example, "persistent activation" (e.g. Philipp & Koch, 2009) suggests that strong activation of the weaker task (i.e., the L2) persists, making the upcoming switch into a dominant task (L1) more difficult. Thus, rather than dealing with overcoming previous *inhibition*, persistent activation is more concerned with current level of *activation* and is rooted in the task set inertia hypothesis from the classic task switch literature (e.g., Wylie & Allport, 2000).

Additional support for a central role of activation, rather than inhibition, has been demonstrated in task switching by evidence of a "stay benefit" rather than a switch *cost*. For example, De Baene and colleagues (2012) found that response times were reduced over a number of stay trials, but not over a number of switch trials, showing a benefit of staying within a task. Additionally, over a series of stay trials, a model of activation, rather than recruitment of additional control processes, better explained neural activation levels.

Of course, these data do not rule out any role of inhibition in language switching, but rather question its role in the scope of a language switching task. In the current findings, it is possible that taxing inhibitory control may have disrupted the adaptation over stay trials, thereby reducing the stay benefit (which, without a baseline to determine directionality of the effect, would be indistinguishable from a reduced switch cost).

Another interpretation of these results is to posit that bilingual language switching does rely on inhibitory control, but of a type fundamentally different from that required to overcome interference induced by PWI. Some support for this interpretation comes from evidence that non-linguistic cognitive control is unrelated to lexical selection in monolinguals (Alario, Ziegler, Massol, & deCara, 2012), which contrasts with significant relationships between cognitive control and language switching in bilinguals (as discussed in the introduction). This finding belies the assumed link between cognitive control and language control more generally, and corresponds with the under-additive effects of language switching and semantic interference found in the current experiment.

Although these findings are inconsistent with the straightforward prediction of a domain-general inhibitory control model of language switching, it is nevertheless possible that PWI and language switching do involve the same underlying inhibitory control processes. One way that shared processes could lead to the apparently independent effects in the current study is if the inhibitory control demands of the two tasks did not overlap in time. That is, these findings could be explained in terms of a bottleneck in dual processes (e.g., Ferreira & Pashler, 2002; Pashler, 1989) whereby some, but not all aspects of a given task require domain general, capacity-limited resources. When capacity-demanding tasks are presented simultaneously, they reach a bottleneck, and must be performed in sequence. Aspects of processing that do not require these resources are automatically processed and therefore do not contribute to, and are not affected by, the bottleneck. In the context of the PWI paradigm, Kleinman (2013) proposed that picture naming is subject to this attentional bottleneck, however word reading is automatically processed and so is unaffected. Thus, in PWI tasks, the distractor word and the naming task can become separated in time, reducing the PWI effect. By this account, the language switch trials in the present experiment might have effectively delayed picture naming while allowing the PWI distractor word to be read, processed, and to no longer be sufficiently active as to induce interference at the point of lexical selection. On the other hand, picture naming should not be significantly delayed during stay trials, when there is no additional conflict; in these trials, both picture naming and distractor words may be processed at the same time, where the interference is readily available to take its toll.

This account fits with our findings of reduced costs during switch trials, where ostensibly the interfering word has had ample time to decay according to a bottleneck account. A bottleneck account would not, however, predict the observed main effect of distractor relatedness, which shows that, regardless of the switch condition, a semantically related distractor word did interfere with lexical selection. Nevertheless, the bottleneck theory may still apply if the delay caused by the switch condition was enough to *reduce*, rather than *remove,* activation from the distractor word relative to a stay trial. If this is the case, the current study's results may yet be consistent with shared resources underlying language switching and interference resolution in the PWI task. Future experiments are necessary to decipher if these findings are in fact due to the bottleneck processes, if they reflect a more specific type of inhibitory control which does not share resources with the PWI task, or if the lack of over-additive interaction between these tasks truly reveals that domain general inhibitory control is not required, at least as it is typically discussed, in bilingual language switching. In any respect, these data lend important constraints to the role of inhibitory control in bilingual lexical access, and suggest revising current models of bilingual production.

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